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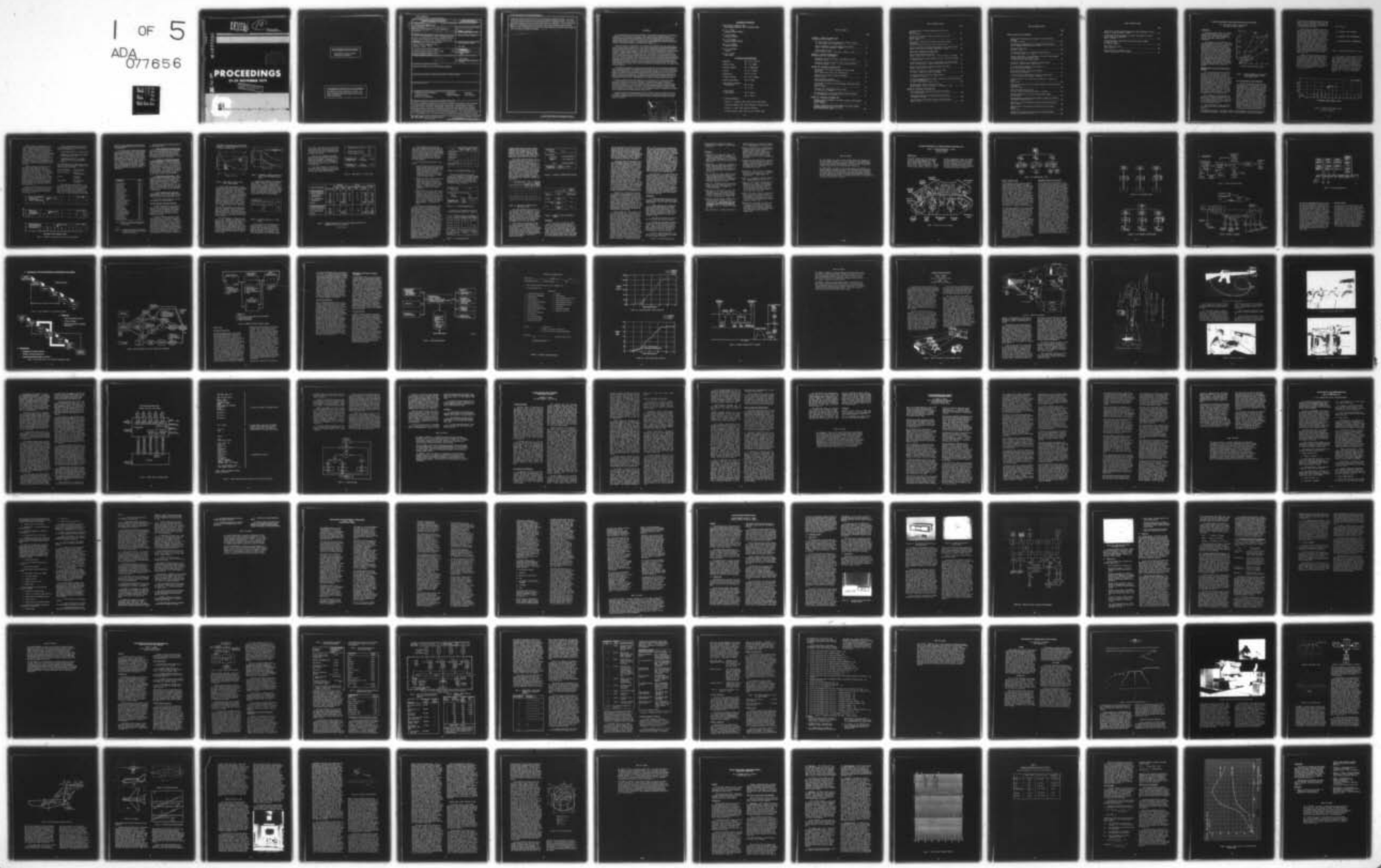

LEVEL II

10

TECHNICAL REPORT
NAVTRAEQUIPCEN IH-316

PROCEEDINGS

27-29 NOVEMBER 1979

1st INTERSERVICE/INDUSTRY TRAINING EQUIPMENT CONFERENCE

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER (14) NAVTRAEQUIPCEN-IH-316	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) (6) 1st Interservice/Industry Training Equipment Conference (1st), Orlando, Florida, 27-29 November 1979.		5. TYPE OF REPORT & PERIOD COVERED (9) Final rept.
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Key Personnel: Naval Training Equipment Center, the Deputy for Simulators (Wright-Patterson AFB), Project Manager for Training Devices, and Industry.		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS Naval Training Equipment Center Orlando, Florida 32813		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS WA 6978
11. CONTROLLING OFFICE NAME AND ADDRESS Technical Manuals Branch (Code N-423) Naval Training Equipment Center Orlando, Florida 32813		12. REPORT DATE (11) November 1979
		13. NUMBER OF PAGES 462
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office) (12) 442		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Conference--NTEC/Industry
Training Analysis
Research & Technology
Engineering
Logistics Support
Utilization
Procurement

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This is a compilation of papers on a variety of technical and training subjects related to training device technology and training methodology. Representatives include sponsors, users, research, development, and procurement agencies and industry. The papers in this report were either presented at the First Interservice/Industry Training Equipment Conference or selected for publication. The Conference was held 27 - 29 November 1979. The First Interservice/Industry Training Equipment (contd)

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Conference was co-sponsored by the Naval Training Equipment Center, Air Force Deputy for Simulators and Army Project Manager for Training Devices. The Naval Training Equipment Center was lead service for the Conference. The Conference is a part of a continuing program to promote cooperation between Government and Industry in the development of effective training equipment and foster an exchange of fresh concepts in training technology. (cont on p 1)

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FOREWORD

The Proceedings of this 1st Interservice/Industry Training Equipment Conference held in Orlando, Florida from 27 - 29 November 1979 represent a major milestone in the evolution in the field of simulation technology and training methodology as they apply to training equipment. Rapid advances in weapon systems technology coupled with the reduced entry level qualifications of recruits present a significant challenge to the services. Training equipment integrated into well-designed training systems will play an increasingly important role in meeting this challenge. With

There are a number of conditions that act as catalysts in increasing the importance being placed on improved training systems by all services. First, there is the increased cost of operational equipment. As these costs increase, alternatives to the widespread use of operational equipment for operator and maintenance training must be developed. Training equipment offers a viable alternative for many training scenarios. Secondly, the increased speed, ranges and cost of weapons severely limit use of actual weapons in training exercises. Training equipment has a demonstrated record for effectiveness in the area of complex weapons such as torpedoes and missiles and advances are now being made in the small arms field. Thirdly, the increased cost of fuel and energy has caused curtailments in operational training, deployments and major exercises. Again, training equipment has a demonstrated performance record in providing effective training at a fraction of the cost associated with the use of the operational systems. Finally, the amount of space available to conduct training exercises is ~~gradually~~ being reduced while the range of weapons is increasing. These two factors, training space and weapons range, are causing a shift in training concepts.

This conference represents the achievement of an objective set by the three principal training equipment-oriented activities within the Department of Defense (DOD), namely, the Naval Training Equipment Center (NAVTRAEQUIPCEN), the Deputy for Simulators (Wright-Patterson Air Force Base), and Project Manager for Training Devices (PM TRADE) under the guidance of the Office of the Under Secretary of Defense for Research and Engineering. The objective was to establish a single major conference in the field of simulator technology and training methodology with greater industry participation in conference planning and execution to improve communications in the training and training systems community.

The papers published in these Proceedings came from all sectors of U.S. Government, foreign governments, industry and the academic community. The subject matter range from research, engineering, management, procurement, instructional systems, user evaluations, to logistic support of systems in the inventory. Each of the authors has devoted considerable effort to prepare his paper. You are commended for that effort. The success of the conference will ultimately be measured by the references made to your papers in the future. These Proceedings represent a comprehensive documentation of training system and training equipment issues of today.

With the emergence of the training equipment field as a major program area within the DOD, these Proceedings, through the cooperative efforts of the authors and their respective organizations, will be the model for the dialogue between users, sponsors, developers, designers and producers of training systems in the future.

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COST-EFFECTIVENESS OF FLIGHT SIMULATORS FOR MILITARY TRAINING

DR. JESSE ORLANSKY AND MR. JOSEPH STRING
Institute for Defense Analyses

INTRODUCTION

The purpose of this paper is to evaluate research and development on the cost and effectiveness of flight simulators used for training. The use of flight simulators for purposes other than training is not considered.*

The advantages of flight simulators for training purposes are well known. They permit close observation of pilot performance and immediate feedback which improves learning; they permit training pilots in many types of malfunctions not often encountered in flight; they are safe and permit training independent of weather, air traffic and the availability of aircraft; they save fuel, ammunition, targets, wear and tear on airplanes and, above all, the lives of pilots. But simulators also have some important disadvantages. Even the most advanced simulators have limited fidelity in external vision, platform motion and flight equations; they cannot provide the motivation and stress possible only in aircraft; and they are expensive to procure and to operate.

OPERATING COSTS OF FLIGHT SIMULATORS AND OF AIRCRAFT

The first question about the cost-effectiveness of flight simulators and aircraft concerns how much they cost to operate. For this purpose, we considered only "variable operating costs" which, by definition, include the costs of fuel, oil and lubrication, base maintenance materials, and that portion of depot maintenance which varies with flying hours and replenishment spares. Variable operating costs do not include the costs of crew and student salaries or for amortizing the purchase of simulators. We were able to find operating cost per hour data for 33 aircraft and simulators, shown in Figure 1. The data are based on actual utilization of aircraft and simulators for FY 1975 and FY 1976.

Most simulator/aircraft operating cost ratios vary from about 5 to 20 percent. The median value is about 12 percent. On the basis of operating costs alone, it is clear that it costs less to operate a flight simulator than the comparable aircraft.

The cost advantage of flight simulators says nothing about their effectiveness for training.

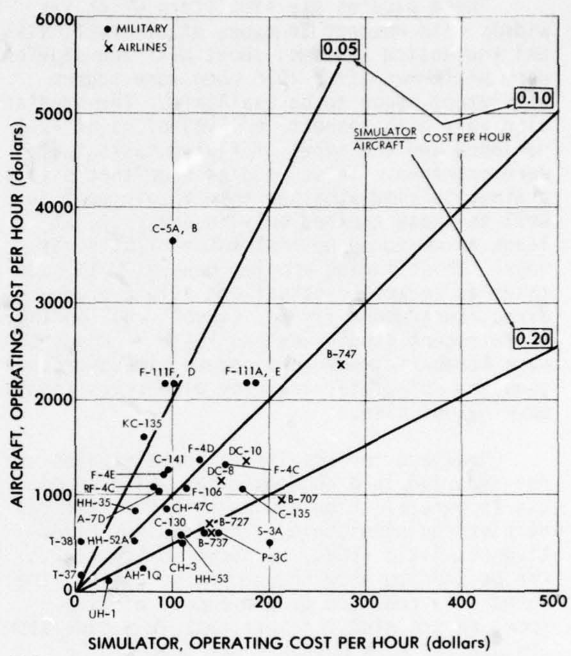

FIGURE 1. VARIABLE OPERATING COSTS PER HOUR FOR 33 SIMULATORS AND AIRCRAFT, FY 1975 AND FY 1976

THE EFFECTIVENESS OF FLIGHT SIMULATORS

There may be many ways to evaluate the effectiveness of flight simulators for use in military training. A favorite one is to have experienced pilots judge whether a simulator flies about the same way the comparable aircraft does. This is the test of "fidelity of simulation." Since we were concerned with the use of flight simulators for flight training, we were particularly interested in whether skills learned in a simulator carry over to an airplane. That is called "transfer of training," which we will define in a moment. Although simulators have been used for training almost since the airplane was invented (at least two flight simulators are known to have been available in 1910), many studies of training are concerned only with how well pilots perform in simulators. For our purposes, we wanted to know how well

*This study was performed for the Deputy Director of Defense Research and Engineering (Research and Advanced Technology). The report is listed in the References at the end of this paper.

pilots trained in simulators perform the same tasks in the air and whether training in simulators saves any flight time. There were 33 studies performed from 1939 to 1977 which provide this type of information.

These studies use simulators which vary widely with respect to types of aircraft, visual and motion systems; about half the studies were performed after 1970 when more modern simulators began to be available. The studies also vary with respect to level of pilot experience and the types of flying tasks that were examined. These studies show that pilots trained in simulators perform in aircraft as well as those trained only in aircraft, at least as measured by instructor pilot's ratings. This finding applies generally to such tasks as cockpit checkout and flight procedures, instrument flying, takeoff and landing; a few recent studies extend these findings to more acrobatic maneuvers and to air-to-ground gunnery. Simulator training also seems to save flight time.

However, the results of these studies are not reported in a common format which permit one to generalize on how much flight time can be saved by simulators. The Transfer Effectiveness Ratio (TER), as shown in Figure 2, can be used to show the amount of flight time saved as a function of the amount of time spent on training the same task in a simulator. Its use for such purposes was proposed by Stanley Roscoe (1971).

$$\text{TER} = \frac{Y_O - Y_X}{X}$$

Y_O = AIRCRAFT TIME, CONTROL

Y_X = AIRCRAFT TIME, EXPERIMENTAL

X = SIMULATOR TIME, EXPERIMENTAL

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FIGURE 2. TRANSFER EFFECTIVENESS RATIO (TER)

Most studies of flight training in simulators, including the more recent ones, do not report Transfer Effectiveness Ratios. However, enough information was available in 22 studies from 1967 to 1977 to compute the 34 TERs shown in Figure 3. These TERs apply, variously, to instrument training, transition training, flight procedures, simulators with or without motion and so on. Overall, the TERs vary from -0.4 to 1.9, with a median value of 0.48. This may be interpreted as follows:

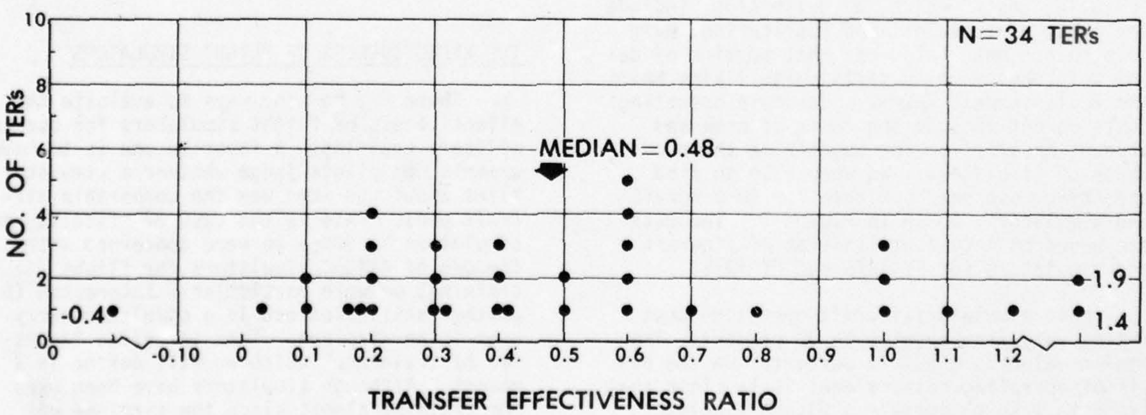

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FIGURE 3. TRANSFER EFFECTIVENESS RATIOS

22 Studies (1967-1977)

Pilots trained in simulators use less flight time than those trained only in aircraft. The median amount of flight time saved is about half (0.48) of the time spent in the simulator. There is one negative value (-0.4) which, if true, means that pilots trained in a simulator in that study used more aircraft time than those not so trained. There is insufficient information on which to explain this case of "negative transfer." It is probably due to use of an inadequate simulator,but it is helpful to understand that not all uses of simulators necessarily save training time.

There are seven cases where the TER is one or more which means that more than one hour of flight time was saved for every hour spent in the simulator. This result should not be too surprising. It is possible to practice a task more often in an hour in a simulator than in an aircraft; e.g., one doesn't have to go around the traffic pattern to shoot a landing; one doesn't have to take time to set up a flight condition as in an airplane, because it can be set up instantly by the computer; one can get more feedback about performance in a simulator than in an airplane, and so on.

However, the highly positive TERS and the one negative TER are extreme values; the middle 50 percent of all values fall between 0.25 and 0.75; the median TER of the entire distribution is 0.48.

The TERs shown previously were divided into three groups based on the experience level of the pilots; i.e.,

highly experienced (i.e., airline pilots)

graduate (i.e., pilots who have already earned their wings), and

undergraduate pilots (i.e., student pilots who have not yet earned their wings).

The experience levels of these pilots, in effect, also describe the use of simulators for different types of training:

Level of Experience	Type of Training
highly experienced	transition flight procedures
graduate	transition instrument
undergraduate	familiarization instrument

The results are shown in Figure 4. Assuming that the TERs are reliable, the figure shows that undergraduate pilots save more aircraft time as a result of using simulators than do more advanced pilots. However, all groups of pilots who use simulators save some flight time. On the other hand, it costs more

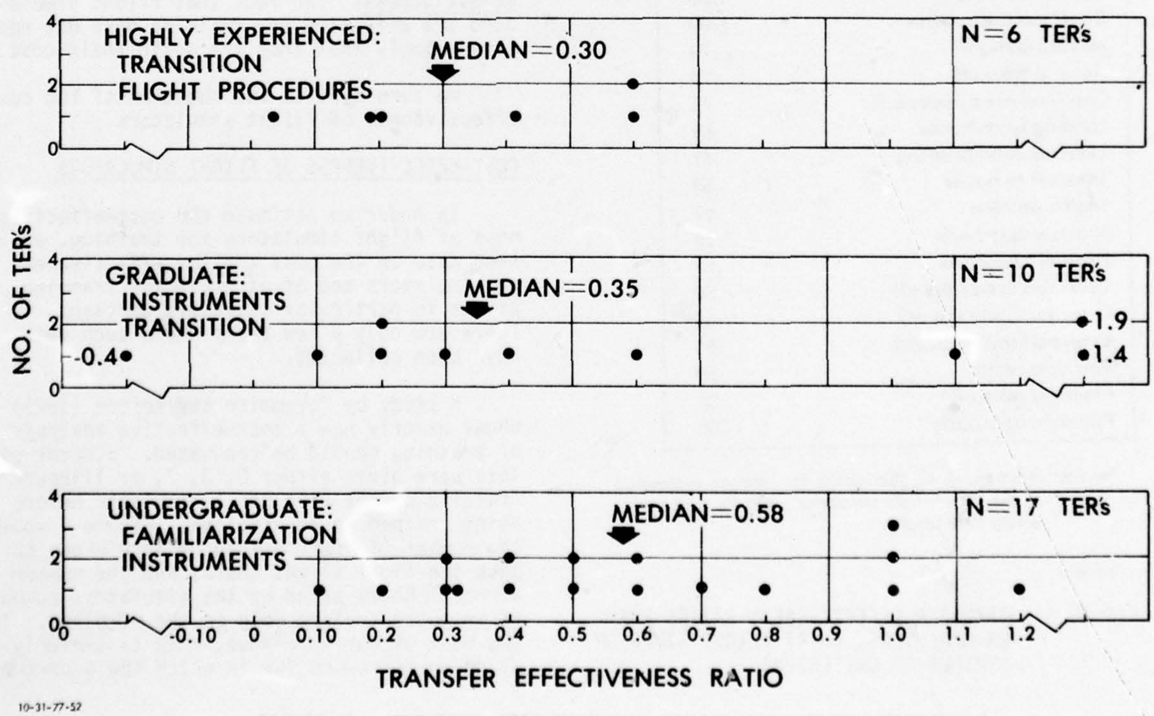

FIGURE 4. TRANSFER EFFECTIVENESS RATIOS AND PILOT EXPERIENCE

per hour to fly an advanced aircraft than one used by undergraduate pilots, but that is not considered here.

In a recent study, Transfer Effectiveness Ratios were determined for 24 different maneuvers when the CH-47 helicopter flight simulator was used for transition training (Holman, 1978). The findings (Figure 5) show that the effectiveness of this simulator varies widely according to the maneuvers on which it may be used for training. The TERs range from 0.0 to 2.8. Clearly, this simulator should not be used for training on some maneuvers. There is also a strong suggestion that this simulator has some limitations for training, probably on tasks that depend significantly on visual simulation.

MANEUVER	TER
Four wheel taxi	2.80
Cockpit run up	1.50
SAS off flight	1.33
Deceleration	1.25
Maximum take off	1.25
General air work	1.00
Steep approach	1.00
Two wheel taxi	1.00
Confined area recon	1.00
Hovering flight	.79
Normal take off	.75
Confined area approach	.75
Landing from hover	.69
External load briefing	.67
Take off to hover	.63
Traffic pattern	.61
Shallow approach	.58
Normal approach	.53
Confined area take off	.50
External load take off	.50
External load approach	.50
Pinnacle recon	.50
Pinnacle take off	.33
Pinnacle approach	.00

Source: Holman, G. L., "Suitability-for-training evaluation of the CH-47 flight simulator", ARI Ft. Rucker, 3 July 1978 (draft).

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FIGURE 5. TRANSFER EFFECTIVENESS RATIOS FOR 24 MANEUVERS, CH-47 FLIGHT SIMLATOR (TRIALS TO CRITERION)

We believe that these studies warrant the following conclusions:

1. Flight simulators save aircraft time. Virtually all studies (21 out of 22) show that the use of flight simulators saves aircraft time. Pilots trained on specific skills in simulators need less time to perform these same skills in aircraft than do pilots trained on the same tasks only in aircraft.

2. Simulators are effective under many different conditions. Simulators have been shown to be effective for training undergraduate and graduate pilots, for training on many different types of aircraft, and for training on different types of tasks (e.g., landing, instrument flight, flight procedures, and flight familiarization). The finding also applies to the effectiveness of simulators with a variety of performance capabilities (e.g., with or without vision, with or without motion).

3. Effectiveness varies widely. There is a wide range in the degree of effectiveness reported with the use of flight simulators. Little systematic attention has been given to examining the factors that may influence the effectiveness of simulators. Since most studies do not use common measures, it is difficult to understand the reasons for the wide range in the effectiveness of different types of simulators or in their use for training on different tasks.

4. Effectiveness does not imply cost-effectiveness. The fact that flight simulators are effective for training does not necessarily imply that they are worth their cost.

We turn next to the question of the cost-effectiveness of flight simulators.

COST-EFFECTIVENESS OF FLIGHT SIMULATORS

In order to estimate the cost-effectiveness of flight simulators for training, we need data on the cost and the effectiveness of simulators and of aircraft for training pilots in particular maneuvers or tasks. There are only a few cases where such data have been collected.

A study by Povenmire and Roscoe (1973) shows exactly how a cost-effective analysis of training should be conducted. Student pilots were given either 0, 3, 7, or 11 hours of training on the Link GAT-1 simulator before being trained in an airplane. Figure 6 shows the number of hours needed by each group to pass the final flight check, and the number of aircraft hours saved by the simulator, compared to those trained only in the airplane. To the best of our knowledge, this is the only study performed so far in which the amount of

time spent in a simulator was varied systematically; all other studies tend to use a fixed amount of simulator time.

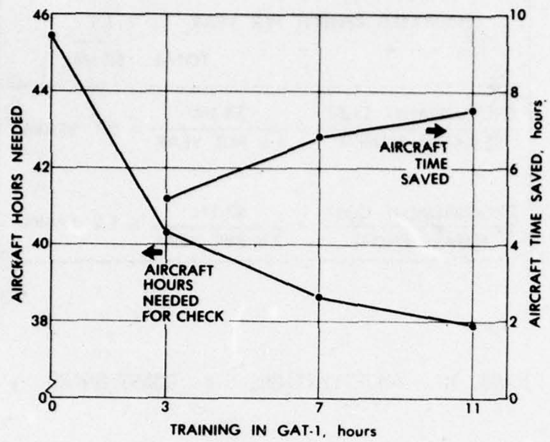

FIGURE 6. HOURS NEEDED FOR FINAL FLIGHT CHECK, PIPER CHEROKEE

Figure 7 shows the Cumulative Transfer Effectiveness Ratio (CTER) and the Incremental Transfer Effectiveness Ratio as functions of the amount of time spent in the simulator (CTER is the same as TER). Both ratios are reduced as the amount of time in the simulator increases. This is an important finding because it permits us to determine when the marginal utility of the simulator has been reached. A useful criterion is the tradeoff between the relative costs of operating a particular simulator and aircraft. In this case, the simulator/aircraft operating cost ratio is $\frac{\$16}{22}$ per hour or 0.73. Therefore, training in the simulator is cost-effective until the Incremental Transfer Effectiveness Ratio drops below the simulator/aircraft operating cost ratio. This occurs at about 4 hours in the GAT-1 for training student pilots to pass the final flight check for a private pilot's license.

The Piper Cherokee is a simple airplane and it is very inexpensive to operate; i.e., $22 per hour. For most military aircraft the operating costs are between about $200 to $1400 per hour. As reported earlier, most simulator/aircraft operating cost ratios for military aircraft range between 0.05 and 0.20. If those ratios applied to the present data, it would have been economical to use the simulator for longer periods, perhaps as long as 10 to 20 hours.

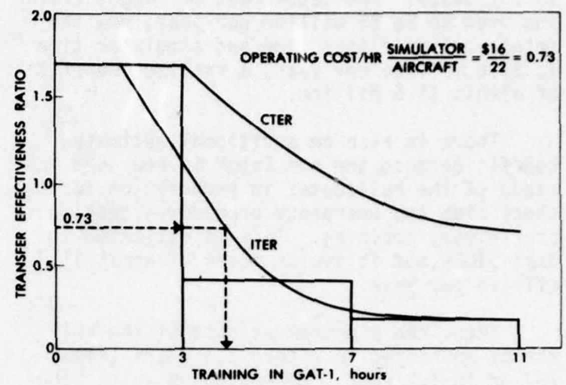

FIGURE 7. INCREMENTAL TRANSFER EFFECTIVENESS RATIO (ITER) AND OPERATING COST RATIO

The Coast Guard operates two helicopters, the HH-52A and the HH-3F (Isley, Corley and Caro, 1974). In 1974, it introduced the Variable Cockpit Training System (VCTS). This simulator has two cockpits and can simulate either or both helicopters; each has a motion base with six degrees of freedom but no visual system. The procurement cost was $3.1M (Figure 8); operating costs of the simulator are very much less than for the helicopters.

PROCUREMENT COST, VARIABLE COCKPIT TRAINING SYSTEM (VCTS)	$3.1M
OPERATING COST PER HOUR (1974 DOLLARS)	
HH-52A	$504
HH-3F	815
VCTS	59

FIGURE 8. HELICOPTER TRAINING, U.S. COAST GUARD

The Coast Guard also introduced a new training syllabus for its new simulator. Figure 9 shows the number of aircraft and simulator hours per pilot required to complete various types of training before and after introduction of the simulator. Aircraft hours required per pilot were reduced

in all cases. The total cost of flight training used to be $3 million per year; now the total cost of flight time and simulator time is $1.6 million per year, a realized benefit of almost $1.5 million.

There is also an additional estimated benefit because the simulator is now used instead of the helicopter in preparation for the check ride and emergency procedures test in proficiency training. This is estimated to cost $106K,but it avoids costs of about $1.1 million per year.

Thus, the procurement cost of the VCTS can be amortized in either 2.1 years (Figure 10) or in 1.2 years, depending on which benefits are used to make this assessment.

PROCUREMENT COST OF VCTS	$3.1M
REALIZED BENEFIT PER YEAR	$1.5M
ESTIMATED BENEFIT PER YEAR	1.1
TOTAL	$2.6M

$$\frac{\text{PROCUREMENT COST}}{\text{REALIZED BENEFIT}} \approx \frac{\$3.1\text{M}}{1.5 \text{ PER YEAR}} = 2.1 \text{ YEARS}$$

$$\frac{\text{PROCUREMENT COST}}{\text{TOTAL BENEFIT}} \approx \frac{\$3.1\text{M}}{2.6 \text{ PER YEAR}} = 1.2 \text{ YEARS}$$

FIGURE 10. AMORTIZATION, U.S. COAST GUARD

TYPE OF TRAINING	PILOTS/YR	BEFORE FLIGHT HRS	BEFORE COSTS (000)	AFTER FLIGHT HRS	AFTER SIMULATOR HRS	AFTER COSTS (000)	BENEFITS (000)
REALIZED BENEFITS							
HH-52A TRANSITION	30	31	$ 469	28	9	$ 439	$ 30
QUALIFICATION	18	78	708	36	11	338	370
PROFICIENCY	300	3	454	0	6	106	348
HH-3F TRANSITION	32	36	939	23	15	628	311
PROFICIENCY	200	3	489	0	8	94	395
TOTALS	580		$3059			$1605	$1454
ESTIMATED BENEFITS							
HH-52A PROFICIENCY	300	3		0	3	53	401
HH-3F PROFICIENCY	200	4.5	734	0	4.5	53	681
TOTALS	500		$1188			$ 106	$1082

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FIGURE 9. ESTIMATED TRAINING COSTS IN THE COAST GUARD BEFORE AND AFTER INTRODUCTION OF THE VCTS SIMULATOR

(1974 Dollars)

In 1977, Browning, Ryan, Scott and Smode (1977) compared the cost and effectiveness of two programs for transition training of naval pilots to fly the P-3C, a four-engine turboprop aircraft used in anti-submarine warfare. The two programs involve the use either of an old simulator (2F69D) or a new one (2F87F); both simulators provide individual and crew training for the pilot, co-pilot and flight engineer.

The following devices were used in the study:

- Cockpit Procedures Trainer (CPT) Device 2C45. Provides training in power plant management and systems procedures for normal and emergency operations. This device is actually an obsolete P-3 operational flight trainer from which flight dynamics, motion, and unneeded systems have been removed.

- Operational Flight Trainer (OFT) Device 2F69D. This OFT is a solid state analog device (1966 era) which simulates flight dynamics, systems, navigation, and communications for P-3A/B aircraft. It provides motion with 3 degrees of freedom, but no visual simulation.

- Operational Flight Trainer (OFT) Device 2F87F. This is a digital device which simulates the P-3C Orion aircraft. It provides motion with 6 degrees of freedom and vision (50° wide x 38° high) by means of a TV model board system (15 nmi x 5 nmi) for low-altitude maneuvers such as takeoff, landing, and instrument approaches. It replaces the 2F69D.

All pilots were newly designated first-tour naval aviators who possessed Standard Instrument Cards. All had completed undergraduate multi-engine training on the S-2, a small two-engine propeller-driven aircraft. Hours given to training in simulators prior to flight are shown in Figure 11: 22 hours in the old program, 40 in the new one. After training in the simulator, performance was measured in the aircraft on 20 of the 45 tasks specified in the Familiarization and Instrument phase of transition training (e.g., engine start, brake fire, abort takeoff, approach, three engine landing). The critical data were the hours required by each group to perform these tasks proficiently in the aircraft; i.e., as judged acceptable by the instructor pilot. The control group required 15 hours in the aircraft per pilot, the experimental group required 9. There was no difference between the groups in flight proficiency in the air. These findings are supported by more recent work at VP-30, (Browning, Ryan and Scott, 1978).

DEVICE	HOURS REQUIRED PER STUDENT		OPERATING COST PER HOUR
	CONTROL N=16	EXPERIMENTAL N=27	
COCKPIT PROCEDURES TRAINER (2C45)	13	16	$104
OPERATIONAL FLIGHT TRAINER (2F69D)	9	--	134
OPERATIONAL FLIGHT TRAINER (2F87F)	--	24	144
AIRCRAFT P-3C	15	9	2284
TOTAL HRS	37	49	
TOTAL COST PER YEAR (200 PILOTS)	$7.1M	$4.6M	

FIGURE 11. ANTI-SUBMARINE WARFARE, P-3C

The new P-3C simulator costs $4.2M (Figure 12). Compared to the control program, the experimental program is estimated to save $2.5M per year (assuming a projected load of 200 pilots per year). On this basis, the procurement cost of the new simulator would be amortized within two years.

PROCUREMENT COST DEVICE 2F87F		$4.2M
OPERATING COSTS PER YEAR (200 PILOTS)		
CONTROL		$7.1M
EXPERIMENTAL		4.6
	SAVINGS	$2.5M PER YEAR
PROCUREMENT COST / SAVINGS PER YEAR	= $4.2M / 2.5M/YR	= 1.7 YEAR

FIGURE 12. P-3C SIMULATOR AMORTIZATION.

An analysis of investment costs also favors the new program (Figure 13). Based on

DEVICE	PRESENT VALUE	CONTROL		EXPERIMENTAL	
		N	COST	N	COST
CPT (2C45)	$1390K	1	$1390K	1	$1390K
OFT (2F69D)	1396	1	1396		
OFT (2F87F)	4225			1	4225
AIRCRAFT P-3C	13.7M	7	95,900	4.2	57,540
TOTAL			$ 98.7M		$ 63.2M
10-YEAR LIFE CYCLE COST (DoD1 7041.3)		$125M		$ 81M	

FIGURE 13. P-3C INVESTMENT COSTS

required flight hours, the control program would require 7 aircraft, the new one 4.2 aircraft. The investment cost of the new program is $63.2 million compared to $98.7 million for the old one. The 10-year life cycle cost of the new program is $81 million compared to $125 million for the old one.

One airline provided an analysis of its current training costs for 1976 for the use of simulators and aircraft (Figure 14). It uses its simulators for training purposes for 26,000 hours each year and, in addition, its aircraft for over 1,100 hours. The cost of these training hours was $6.8 million in 1976. This airline estimated what it would cost if all these training hours had to be performed only in aircraft. That total would be about $32.1 million a year. By the use of simulators, this airline estimates that its annual training costs are about 21 percent of what they would be if they had to depend only on aircraft.

AIRCRAFT	TOTAL TRAINING HOURS		COSTS		SIMULATOR & AIRCRAFT AS PERCENTAGE OF AIRCRAFT-ONLY COSTS
	SIMULATOR	AIRCRAFT	SIMULATOR & AIRCRAFT (ACTUAL)	AIRCRAFT ONLY (ESTIMATE)	
A	3,511	186	$1.2M	$ 6.0M	19%
B	8,997	272	2.1	10.6	20
C	12,277	547	2.9	11.8	25
D	1,262	118	0.6	3.7	17
TOTAL	26,047	1,123	$6.8M	$32.1M	21%

FIGURE 14. ANALYSIS OF TRAINING COSTS BY ONE AIRLINE, 1976

The flight simulators used by this airline cost $17.5 million (Figure 15). The airline estimates that it saves $25 million per year by the use of these simulators compared to what it would cost if it had to use only aircraft for training. This airline estimates that the savings it realizes by the use of simulators would permit it to amortize their procurement cost in less than 9 months.

These studies are summarized in Figure 16. Only a few reports have examined the cost-effectiveness of flight simulators in actual practice. The findings support the use of simulators. Use of the Navy P-3C simulator and the Coast Guard VCTS simulator saved sufficient flight time to amortize procurement costs within two years. An analysis provided by an airline suggests an even shorter amortization period.

PROCUREMENT COST	
SIMULATORS	$17.5M
COST OF TRAINING	
AIRCRAFT ONLY	$32.1M PER YEAR (ESTIMATE)
SIMULATORS AND AIRCRAFT	6.8 PER YEAR (ACTUAL)
SAVINGS	$25.3M PER YEAR (ESTIMATE)

$$\frac{\text{PROCUREMENT COST}}{\text{SAVINGS PER YEAR}} = \frac{\$17.5\text{M}}{\$25.3\text{M PER YEAR}} = 8.3 \text{ MONTHS}$$

FIGURE 15. ESTIMATES OF AMORTIZATION (AIRLINE)

	APPLICATION	PILOT LOAD	ESTIMATED AMORTIZATION OF SIMULATOR
PRIVATE PIPER CHEROKEE GAT-1	FINAL FLIGHT CHECK	—	ESTABLISHES OPTIMUM USE OF SIMULATOR
NAVY P-3C 2F87F	TRANSITION TRAINING	200	2 YEARS
COAST GUARD HH-52A HH-3F VCTS	TRANSITION, PROFICIENCY TRAINING	500	2 YEARS
AIRLINE	TRANSITION, RECURRENT TRAINING	—	9 MONTHS

FIGURE 16. SUMMARY OF COST-EFFECTIVENESS STUDIES

DISCUSSION

It is no surprise to find that flight simulators cost less to operate than do aircraft. Most simulator/aircraft operating cost ratios fall in the range of 0.05 to 0.20. The use of flight simulators appears to save flight time in aircraft. The range of these values, expressed as Transfer Effectiveness Ratios, varies from close to zero to well over one, with a median at about 0.50. Thus, there is a clear implication that flight simulators

can be cost-effective for training providing careful attention is given to the tasks and maneuvers for which they are used and that flight simulators are not used beyond the point of marginal utility for these maneuvers. Only a few studies of cost-effectiveness have actually been conducted. Here, it appears that the cost of procuring flight simulators can be amortized within about two years.

A few words should be said about some recent developments that can significantly affect the cost-effectiveness of flight simulators. The first concerns the need for platform motion in flight simulators. A six degree of freedom synergistic motion platform can cost up to $0.6 million. A series of studies since 1974 have shown that there is no difference in performance in aircraft between pilots trained in simulators with motion and pilots trained without motion (Koonce, 1974; Jacobs and Roscoe, 1975; Woodruff and Smith, 1974; Gray and Fuller, 1977; Woodruff, Smith et al., 1976; Martin and Waag, 1978). Although more work remains to be done, it appears that modern flight simulators for center thrust aircraft, with good visual systems, do not need platform motion. Recent procurements of F-16 and A-10 simulators by the Air Force do not include platform motion. It is still an open question whether platform motion is needed in simulators for wide-bodied aircraft.

Incidentally, a concern with improving the fidelity of flight simulators led to the improvement of platform motion over the past 15 years. It is, of course, true that pilots perform better in simulators with motion than in simulators without motion. Until Koonce's study in 1974, no one had thought to ask whether platform motion in simulators contributes anything to performance in aircraft. The answer so far seems to be "not much." It also suggests that, except possibly to improve pilot acceptance, the test of fidelity may not always give us a good answer.

Visual systems for flight simulators are very impressive devices. So is their cost, which is now in the range of $6 to $8 million per copy. New computer-generated visual systems can provide types of training in simulators that have not been possible up to now. They can present scenes needed, for example, for training in aerial refuelling, air-to-air combat, and nap-of-the-earth flying. The real question concerns the degree of realism required to make visual displays useful for such types of training. Very little data are now available to help us specify the visual requirements for the most expensive component in a modern flight simulator. There is one study in which Air Force pilots were trained to land a B-707 using one of three different visual simulation systems and then measured for their ability to land a KC-135 aircraft, the tanker version of the B-707 (Thorpe, Varney et al., 1978). The visual scenes were produced by a day computer-generated imagery (CGI) system, a day TV model board system and a night-only computer-generated imagery system. Pilot performance on landing the aircraft was superior for those trained on the CGIs to those trained on the TV model board; there was no difference between the two CGI systems as far as landing performance is concerned. If we accept the results of this one study, the less expensive, night-only CGI is all we need for training pilots how to land. In all fairness, further studies on other maneuvers and other types of simulators are needed before we can specify what type of visual imagery is good enough for various types of training. Here again, the image with the greatest fidelity and cost may not be all that necessary.

One final point. It is quite likely that flight simulators will be found to be cost-effective and as a result, there may be more pressure to reduce flying hours. Flight simulators, however useful, are not a substitute for training in aircraft. Military training must proceed from simulators to aircraft and there is some minimum amount of flight time required below which one cannot go. This is necessary to maintain combat skills and to exercise support systems, such as maintenance and command and control, on which military readiness depends. More attention must clearly be given to establish what these minimum flying hours should be.

CONCLUSIONS

1. Flight simulators cost less to operate than do aircraft; most simulator/aircraft operating cost ratios fall within the range of 0.05 to 0.20.

2. Flight simulators save flight time. Transfer Effectiveness Ratios vary widely, with a median value of about 0.50. This means that about half the time spent in simulators shows up as savings in flight time, with variations probably due to type of simulator and type of maneuvers for which the simulator is used.

3. The cost of procuring flight simulators can be amortized in about two years.

4. Research and development is needed to improve our knowledge about the optimum use of simulators for various types of flying tasks. There is also a need to examine the need for platform motion in simulators for wide-bodied aircraft and for the degree of realism needed in new visual displays.

5. There is a need to establish the marginal utility of flight simulators when used for various types of training.

6. There is a need to establish the

minimum amounts of flying hours needed to maintain military readiness in various types of aircraft.

REFERENCES

Browning, R.F., L.E. Ryan, P.G. Scott, "Utilization of Device 2F87F OFT to Achieve Flight Hour Reductions in P-3 Fleet Replacement Training," TAEG Report No. 54, Training Analysis and Evaluation Group, Orlando, Fla., April 1978.

Browning, R.F., L.E. Ryan, P.G. Scott and A.F. Smode, "Training Effectiveness Evaluation of Device 2F87F, P-3C Operational Flight Trainer," TAEG Report No. 42, Training Analysis and Evaluation Group, Orlando, Fla., January 1977.

Gray, T.H., and R.R. Fuller, "Effects of Simulator Training and Platform Motion on Air-to-Surface Weapons Delivery Training," AFHRL-TR-77-29, Williams Air Force Base,Ariz. Flying Training Division, Air Force Human Resources Laboratory, July 1977.

Holman, G.L., "Suitability-for-Training Evaluation of the CH-47 Flight Simulator," Army Research Institute, Fort Rucker, Ala., 3 July 1978 (draft).

Isley, R.N., W.E. Corley and P.W. Caro, "The Development of U.S. Coast Guard Aviation Synthetic Equipment and Training Programs," FR-D6-74-4, Human Resources Research Organization, Fort Rucker, Ala., October 1974.

Jacobs, R.S. and S.N. Roscoe, "Simulator Cockpit Motion and the Transfer of Initial Flight Training" in New Concepts for Training Systems, 8th NTEC/Industry Conference Proceedings, Naval Training Equipment Center, Orlando, Fla., p. 113-122, 18-20 November 1975.

Koonce, Jefferson M., "Predictive Validity of Flight Simulators as a Function of Simulator Motion," Human Factors, 21, 215-223, 1979.

Martin, E.L. and Waag, W.L., "Contributions of Platform Motion to Simulator Training Effectiveness: Study I--Basic Contact," AFHRL-TR-78-15, June 1978, Study II Aerobatics, AFHRL-TR-78-52, September 1978, Williams Air Force Base, Ariz.: Flying Training Division, Air Force Human Resources Laboratory.

Orlansky, Jesse and Joseph String, "Cost-Effectiveness of Flight Simulators for Military Training," IDA Paper P-1275, Institute for Defense Analyses, Arlington, VA, August 1977, (3 volumes) DDC No's. AD A052,801, AD A049-979, AD C013-000.

Povenmire, H.K., and S.N. Roscoe, "Incremental Transfer Effectiveness of a Ground-Based Aviation Trainer," Human Factors, 15, 534-542, 1973.

Roscoe, S.N., "Incremental Transfer Effectiveness," Human Factors, 14, 363-364, 1971.

Thorpe, J.A., N.E. Varney, R.W. McFadden, W.D. LeMaster and L.H. Short, "Training Effectiveness of Three Types of Visual Systems for KC-135 Flight Simulators," AFHRL-TR-78-16, Williams Air Force Base, Ariz., Flying Training Division, Air Force Human Resources Laboratory, June 1978.

Woodruff, R.R. and J.F. Smith, "T-4G Simulator and T-4 Ground Training Device in USAF Undergraduate Pilot Training," AFHRL-TR-74-78, Williams Air Force Base, Ariz., Flying Training Division, Air Force Human Resources Laboratory, November 1974.

Woodruff, R.R., J.F. Smith, J.R. Fuller and D.C. Weyer, "Full Mission Simulation in Undergraduate Pilot Training: An Exploratory Study," AFHRL-TR-76-84, Williams Air Force Base, Ariz., Flying Training Division, Air Force Human Resources Laboratory, December 1976.

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SOFTWARE MANAGEMENT OF A COMPLEX WEAPON SYSTEM SIMULATOR

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INTRODUCTION

This paper presents the history and lessons learned in the development and implementation of the computer programs for a large complex Weapon System Trainer (WST). The WST is a high fidelity simulator of the B-52 and KC-135 crew stations (Figure 1). The WST includes visual, motion, sound, and a highly flexible instructional system. The contract for the development of a production prototype unit began in mid-1977. The development team consisted of the Boeing Company, Wichita as integrator and several subcontractors responsible for the various stations and systems as indicated in Figure 2.

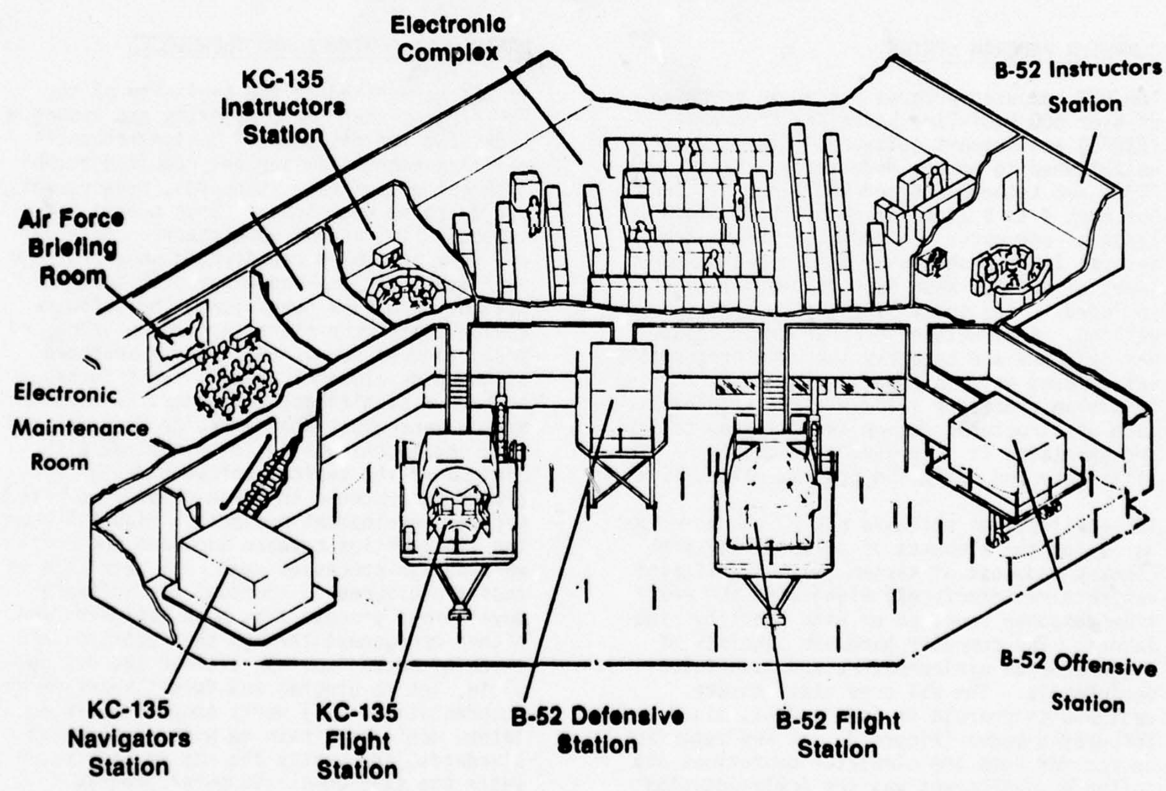

FIGURE 1 B-52/KC-135 WST TEST COMPLEX

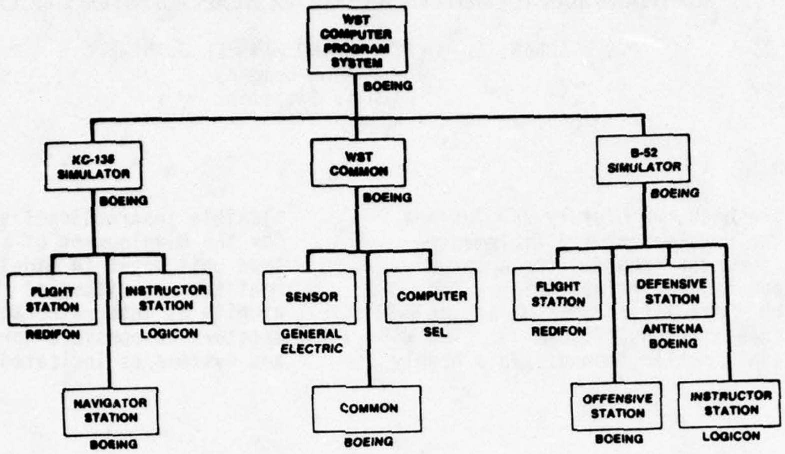

FIGURE 2 WST COMPUTATIONAL SYSTEM

COMPUTER PROGRAM SYSTEM

The WST computer program system is composed of over 600 Real-Time Operating Programs (RTOPS) and support software. Standards were established to ensure modularity so that most RTOPS are between 100 and 400 lines of codes. For each 4 to 5 lines of code, there are 3 lines of comments. In addition, there are several large programs of one to two thousand lines of codes. When support programs are included, the total lines of code exceed one million. A structured Fortran preprocessor was selected and assembly language programming was allowed only in rare special cases. This S-Fortran processor allowed direct implementation of structured design and was easy to read and maintain; it increased programming efficiency and increased program reliability.

The applications software can be characterized as having the elements of a large real-time command and control system (with significant man/machine interfaces) along with the real-time response required of high fidelity simulators. The computer hardware consists of Systems 32/55 minicomputers and associated peripherals. The WST crew stations are designed to operate in independent, mixed and integrated modes (Figure 3). A key interface design for both the simulator operations and software development was the implementation of a shared memory datapool arrangement. This shared memory scheme (Figure 4) makes it possible to change the software design and revise simulator operations with minimum design impact. This datapool design also made it possible to design, code, and test the software so that programmers need use only mnemonic names for all variables without knowing the locations and detailed characteristics of each variable.

MANAGEMENT CONTROLS AND TECHNIQUES

It was recognized at the beginning of the WST Program that the complexity and amount of code, and the division of design responsibilities among team members, required establishment of software standards, measurements, and tracking techniques. Both budget and schedule limitations were severe. Although the team assembled represented some of the most qualified and experienced in terms of design, data, and operations, the software design teams were characterized by young and inexperienced personnel. (Now a seasoned software development group.) This turned out to have a significant advantage, in that the proper management standards, procedures, and tracking techniques could be applied with a minimum of the typical software design syndromes encountered in large complex computer program development projects. Figure 5 shows the similarities between hardware and software design processes used. We were able to resist pressures to shortcut the software development process from both designers and higher management through the reporting and tracking mechanism. We avoided the 90% complete, let me program and forget about design documentation, I'll worry about interfaces later, don't constrain me with programming standards, and that's the way we did it ten years ago syndromes. Computer program technical integrity was maintained through technical walkthroughs on a module basis, frequent design reviews, module tests and verification procedures, subintegration test procedures and documented test results. The documentation mechanism used was an adaptation of the milestone system (Figure 6).

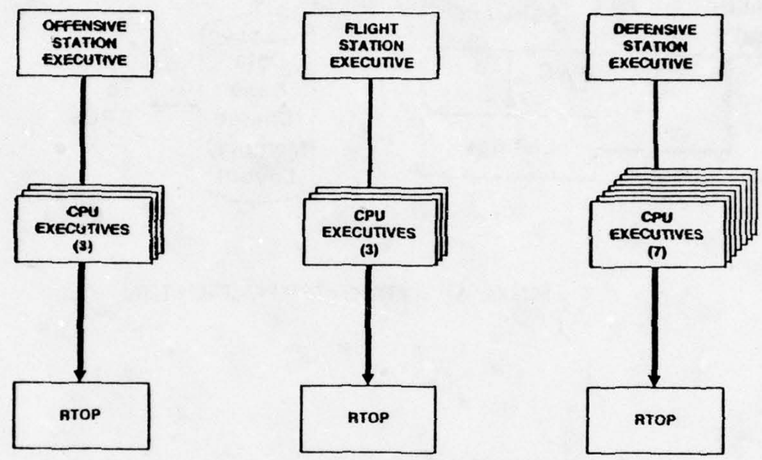

FIGURE 3a B-52 INDEPENDENT MODE

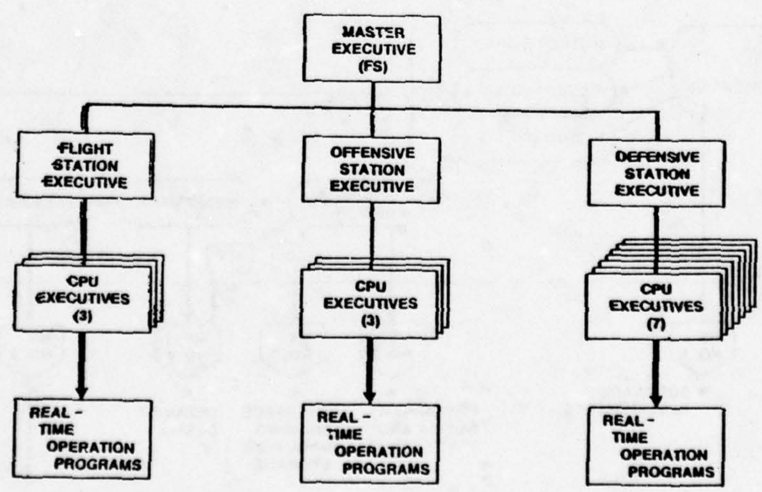

FIGURE 3b B-52 INTEGRATED OPERATION MODE

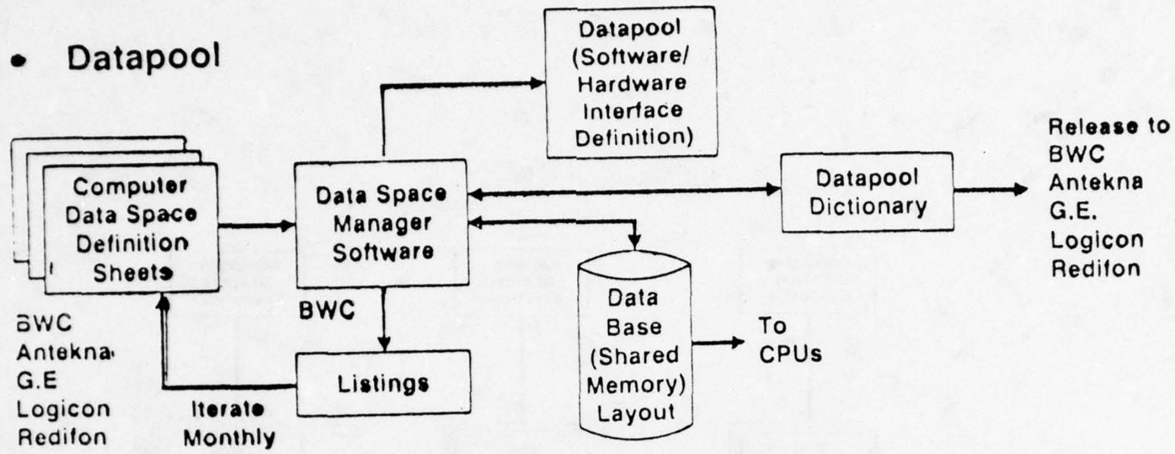

FIGURE 4 SOFTWARE INTERFACE CONTROL

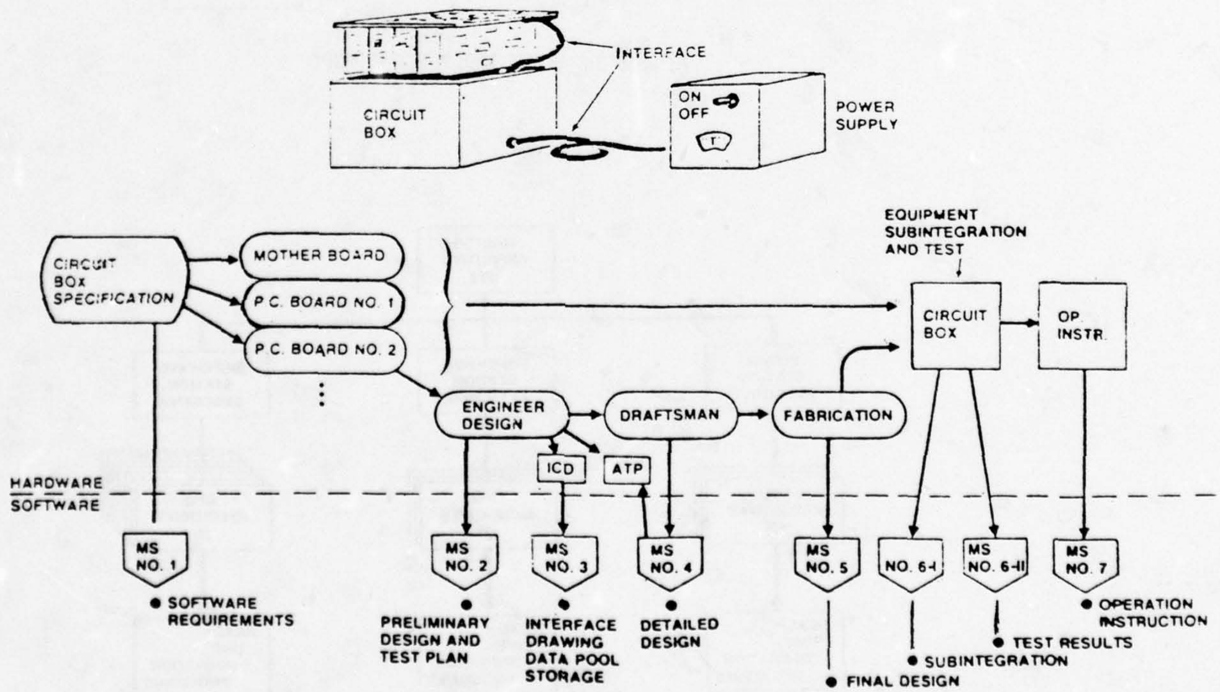

FIGURE 5 SOFTWARE VS HARDWARE

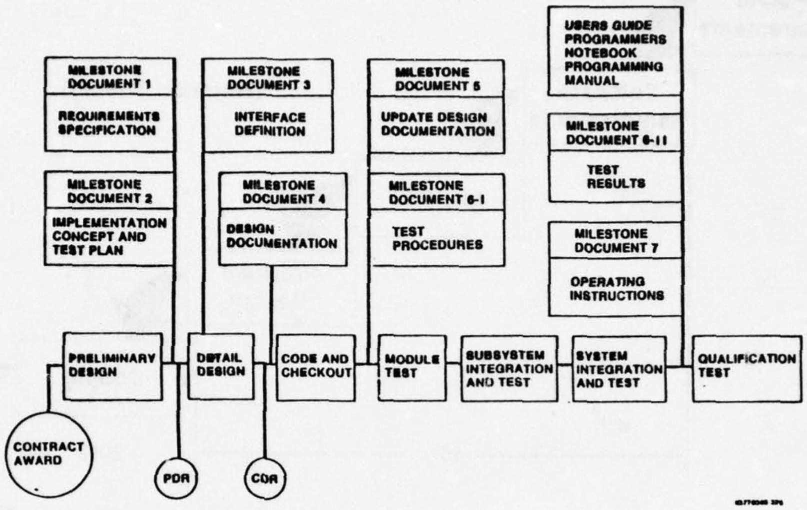

FIGURE 6 MILESTONE DOCUMENTATION

The other key management action was to apply the same engineering design disciplines used successfully by Boeing for hardware and airplane systems integration to the formal software development process shown in Figure 7 (and we stuck to it). We modified the waterfall theory as shown in Figure 8, by providing feedback through the mechanism of completely revised and approved documentation prior to allowing coding, and the implementation of formalized computer program change procedures that provided traceability and control of all changes resulting from module and system testing (Figure 9). A committment was made to include a quality assurance role early in the software development process prior to module testing instead of at the verification test procedure effort late in the program. This helped maintain configuration control and audit trails.

INTERFACE CONTROL

A key mechanism for ensuring that the software design was tied to the simulator hardware design was to use the datapool mnemonics as the hardware and software interface identifier (Figure 10). All wiring connectors and signals were identified and correlated to the variable mnemonics. The datapool was maintained and controlled by the adaptation of a commercially available data base manager program. By insisting that all software development standards, and all interfaces with shared memory be defined among all team members, the tasks of hardware/software integration and test were made possible with a minimum of the problems encountered in this phase of software development.

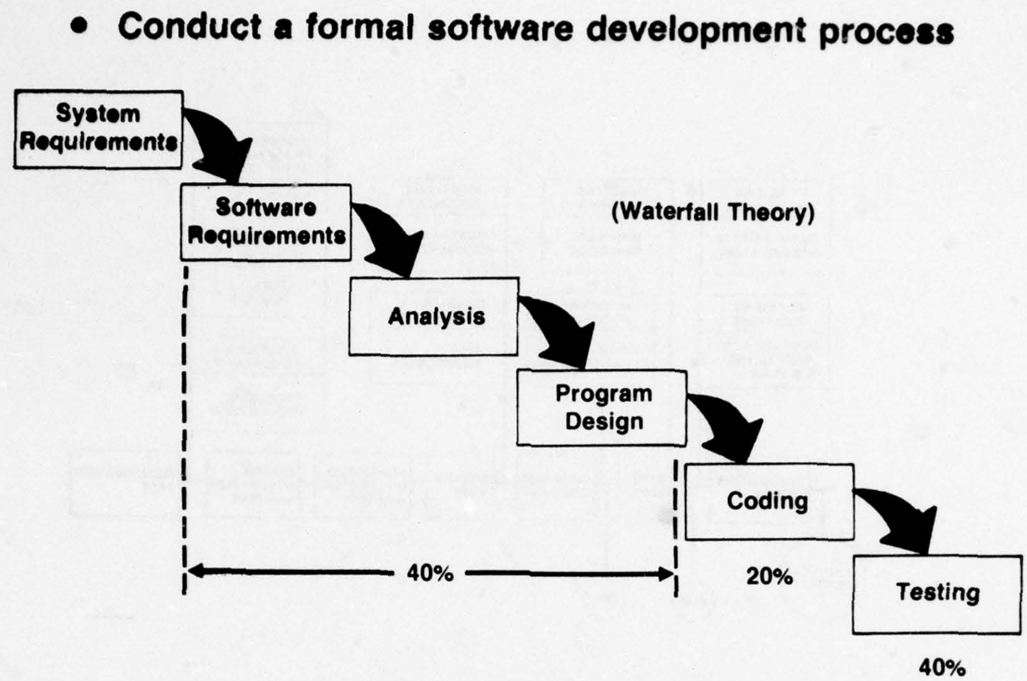

FIGURE 7 FIRST PREREQUISITE TO INTEGRATING SOFTWARE

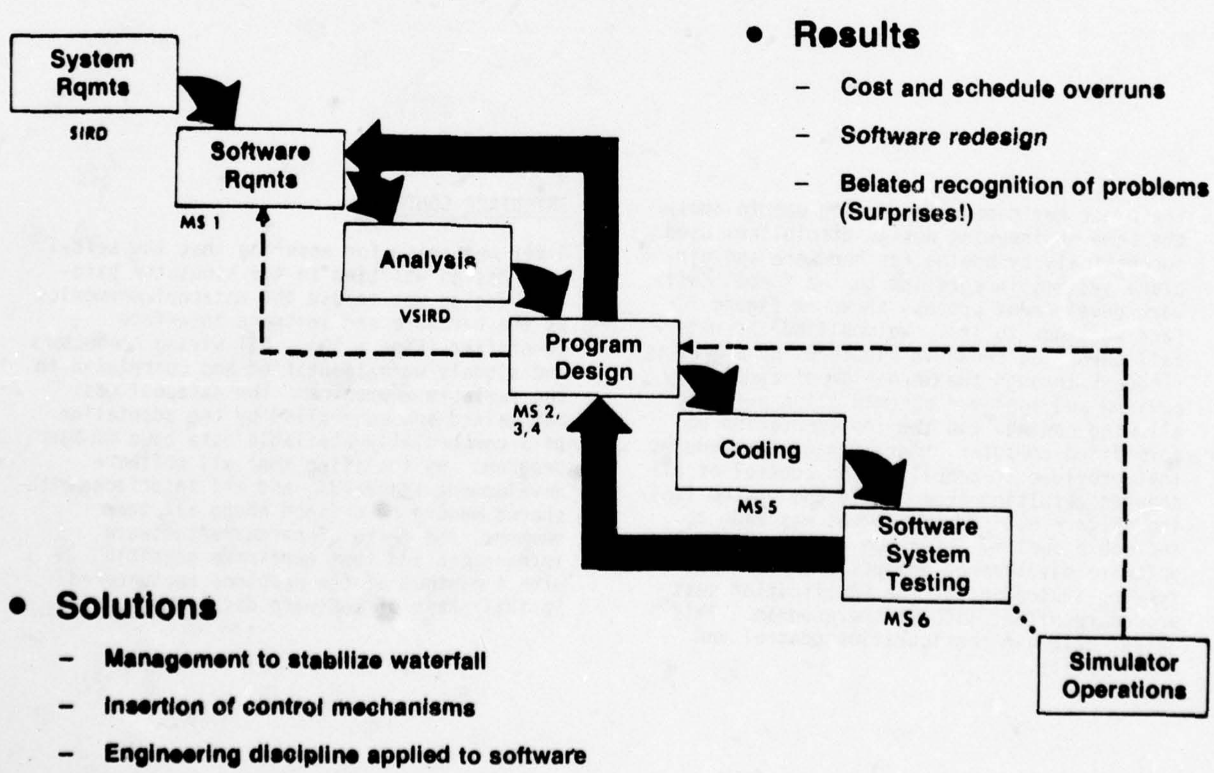

FIGURE 8 WATER FLOWS UPHILL IN THE SOFTWARE DEVELOPMENT PROCESS

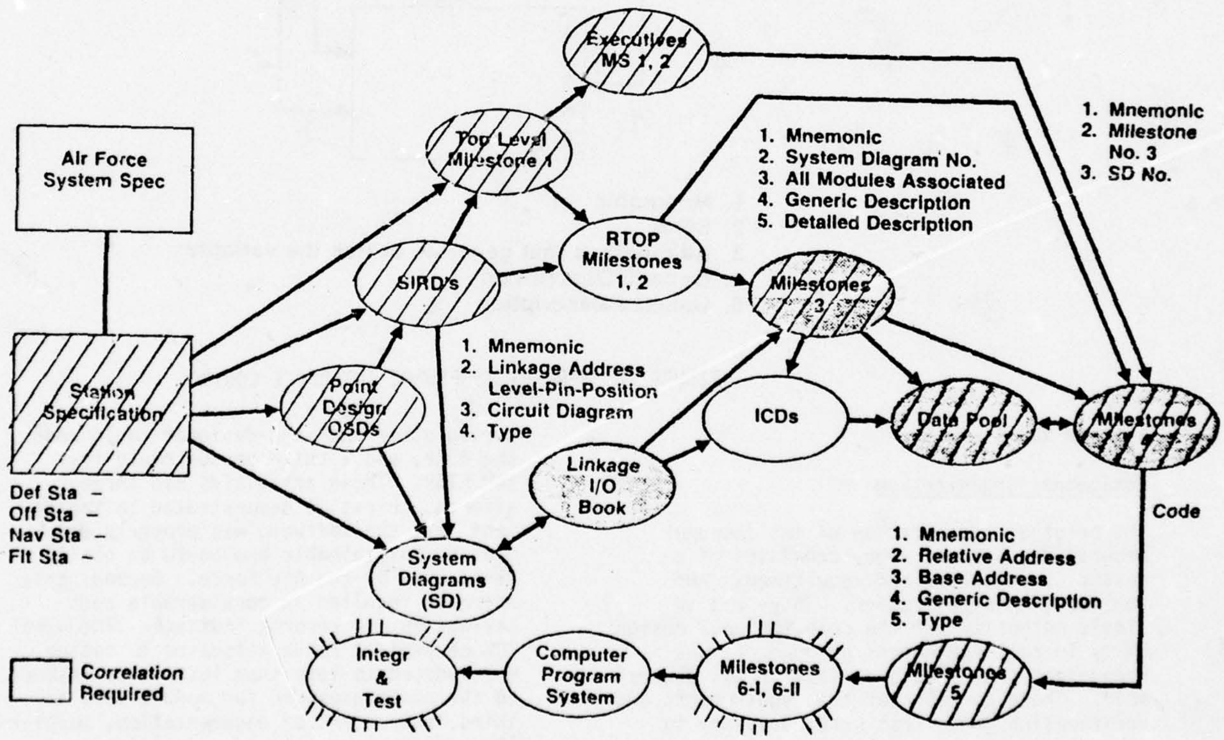

FIGURE 9 DESIGN TRACEABILITY AND DATA CORRELATION REQUIREMENTS

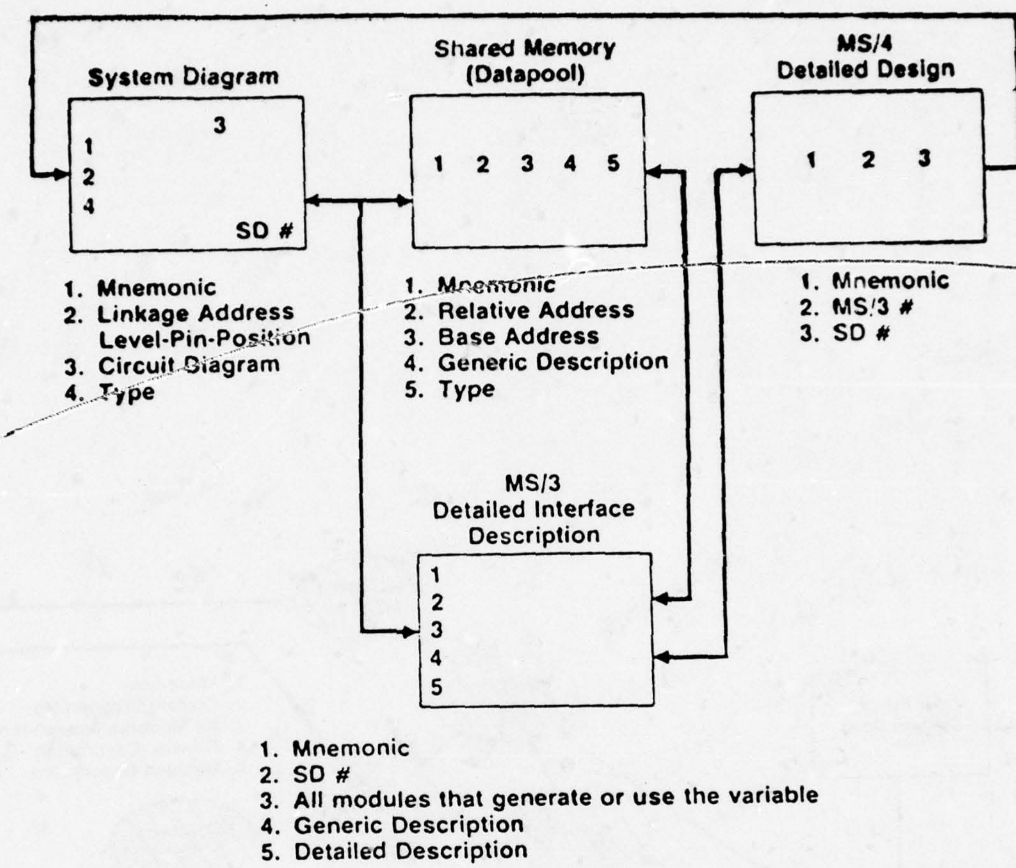

FIGURE 10 HARDWARE/SOFTWARE INTERFACE CONTROL

PROBLEM AREAS

Management Organization

The original organization of the computer program development group consisted of a design organization and requirements and verification organization. There was no single authority for the computational design. Early in the development program, it was recognized that this organization was unworkable. Those portions of the requirements and verification group that were necessary to provide the checks and balances were retained and placed under the computer program design manager. The main function of this group was to ensure the integrity of the design by thorough documentation review and design test. Later in the development schedule, this group shed its role as watchdog and performed most of the module coding and testing functions which proved the modularity concept of the software design. Most important to us, this proved that with the proper design documentation and adherence to programming standards a person other than the designer could code the RTOP, and a third person could test the RTOP. These activities had three effects. First it demonstrated to management that the software was properly documented, maintainable and could be easily taken over by the Air Force. Second, this approach resulted in considerable cost savings as our records indicate. The usual 20% of project funds allocated to coding was reduced to less than 15%, which included the costs expended for module testing. Third, the extent of documentation, modularity, and testing allowed a decision to be made to omit the usual extensive sub-integration of software. This function was combined with the Hardware/Software Integration (HSI) tasks. The result was considerable savings in dollars and achieved a very challenging schedule by allowing overlap of the design, code and test phases of the software development and allocation of personnel to these functions cost-effectively.

Another early organizational mistake was

placing of the documentation of the mathematical models in a systems engineering organization. This organization produced the Software Implementation Requirement Documents (SIRDS) which, although adequately detailed on a module level, failed to include sufficient system integration considerations and test requirements in the math models. This deficiency was overcome by the adherence of the software designers to module design and testing integrity. The lesson learned is that development of the math models should be placed under the software development manager to ensure sufficient interchange with software designers, and maintaining of standards to facilitate subsystem and HSI testing downstream. The Systems Engineering function is to define requirements and determine allocation between hardware and software.

Subcontract Integration

A basic integration problem was the lack of adequate interface definition which resulted in false starts and/or late starts on the software design. Interface control documents including datapool definitions were not properly prepared early enough in the project. Correcting this situation required costly establishment of task forces and development of data base generation and control techniques. Earlier and proper data base management and coordination with team members, all of whom were at least 2000 miles away (including England), would have prevented considerable difficulity in the HSI and test activities. The fact that the basic scheme of shared memory design was sound allowed successful attainment of the software design and integration. Other key techniques for control and integration of subcontractor software was to contractually impose the same standards on them, to provide executive and support software, and to provide configuration control and object verification procedures to support software testing (Figure 11).

Measurement and Tracking of Software Development

As stated above, the early establishment of software design and development standards combined with the modular design allowed tracking of progress at the individual RTOP level. The milestone documentation system shown previously in (Figure 9) also allowed the further tracking of each RTOP at each milestone level. Insistence was maintained on complete and thorough documentation prior to code and test and complete review as shown in Figure 12 (requiring 3 signatures) at the working level. Work charts (Figure 13) were established and updated weekly for each simulator station and used by management to monitor progress and reveal problem areas. As work fell behind, management actions, decisions, and recovery plan were implemented. Extensive tracking by all levels of management on daily and weekly intervals was included and a computerized program planning and control system was established showing the start and completion dates of each event, down to the individual milestone document.

CONCLUSIONS BY BWC

A complex simulator software development project can be successfully accomplished on schedule and within budget by adhering to engineering design disciplines and management controls. There are no shortcuts to design and development of software. The key to design integrity and configuration control is to maintain formal quality assurance through established mechanism as shown in Figure 14. Documentation of design prior to coding is essential. A popular belief that programming is an uncontrollable intellectual exercise, that defies application of engineering disciplines and management control techniques, is erroneous as we have proven in the B-52/KC-135 Weapons Systems Trainer. Detail tracking of software development progress is required using realistic measures of progress such as documentation, code and testing of the smallest definable module.

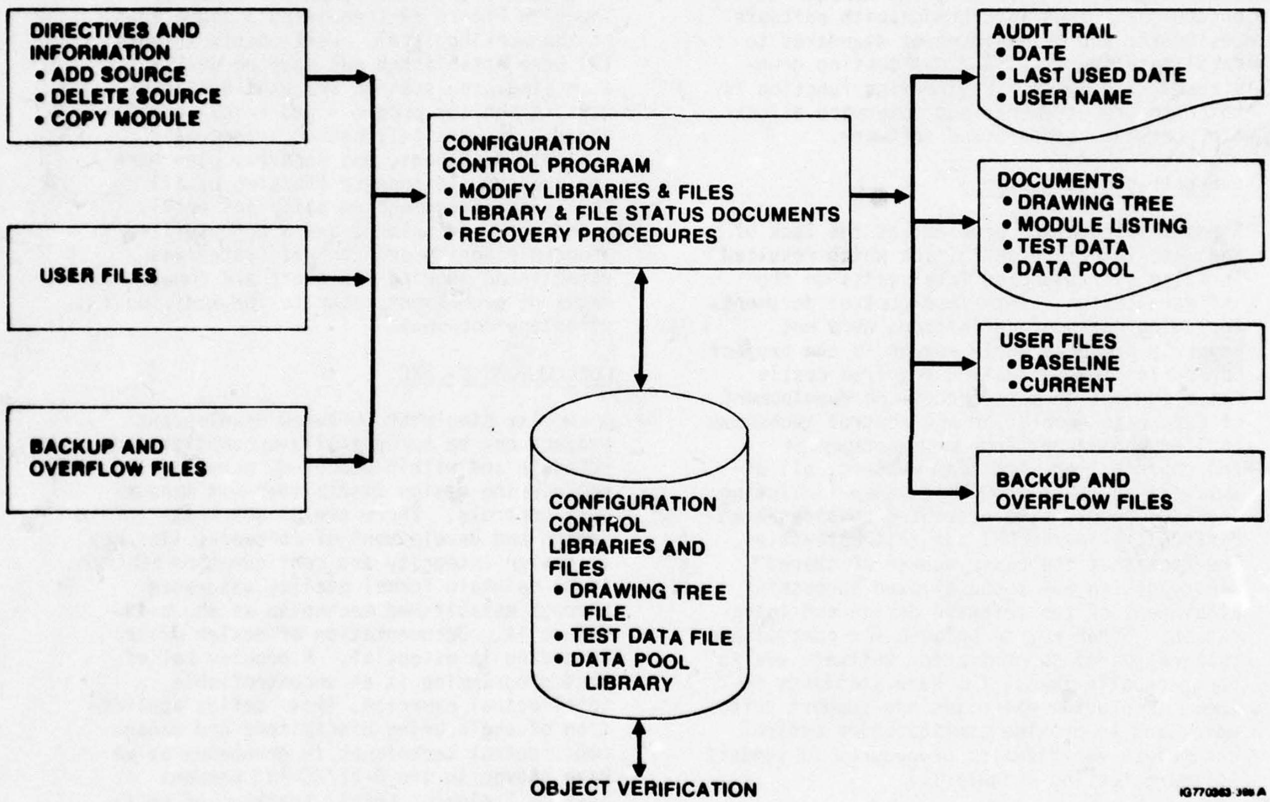

FIGURE 11 CONFIGURATION CONTROL

TECHNICAL WALKTHROUGH REPORT

MODULE NAME ______________________ DRAWING NO. ______________ DATE _________

PRELIMINARY DESIGN _____ DETAILED DESIGN _____ CODE _______________

o Walk through material and work off old comments list.

o Create comments list.

CHECK LIST

_____ Functional Description
_____ Requirements Referenced
_____ Malfunctions
_____ I/O Definition
_____ Time & Memory Allocations
_____ User Information
_____ Variable Description
_____ Design Meets Requirements
_____ Structure Chart
_____ Design Meets Standards
_____ Flow Diagrams
_____ Test Plan/Procedures
_____ No Extra Requirements
_____ No Division by Zero

_____ Header
_____ Program Name
_____ User Information Consistent
_____ Variable Descriptions
_____ Time & Memory Allocations
_____ Code Represents Design
_____ Commenting
_____ Code Meets Standards
_____ Checkout Sufficient

Decision:

_____ Accept as is
_____ Revise (no further walkthrough)
_____ Revise and schedule another walkthrough

Signatures:

____
Lead

Presentor (Design Staff)

____
Reviewer (Tech Staff)

FIGURE 12 TECHNICAL WALKTHROUGH REPORT

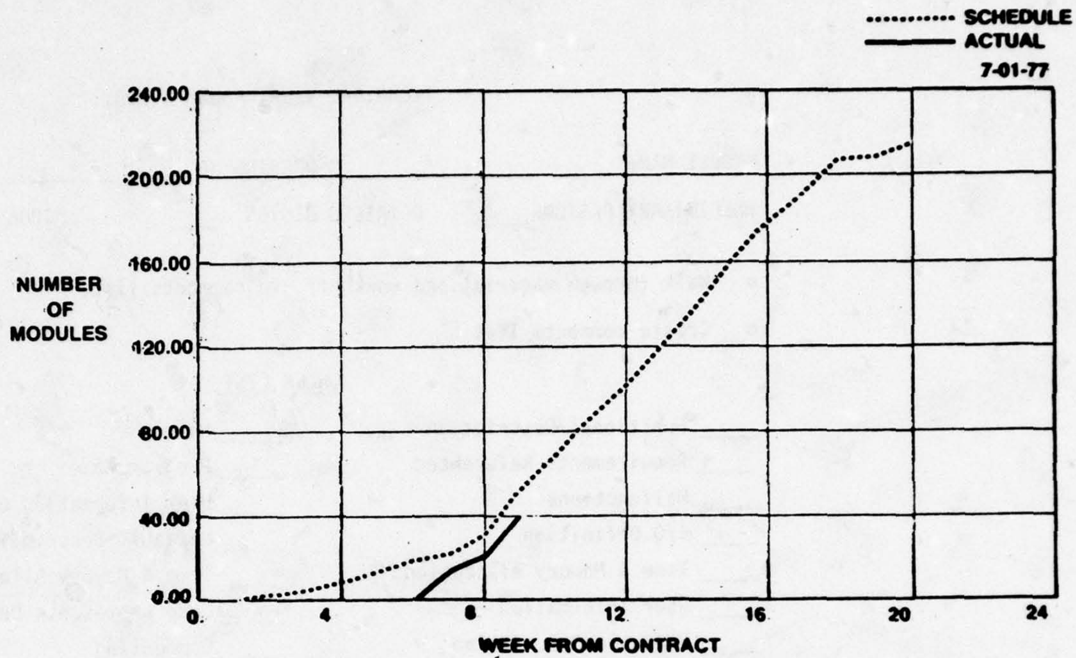

FIGURE 13a TYPICAL MILESTONE 1 STATUS VISIBILITY

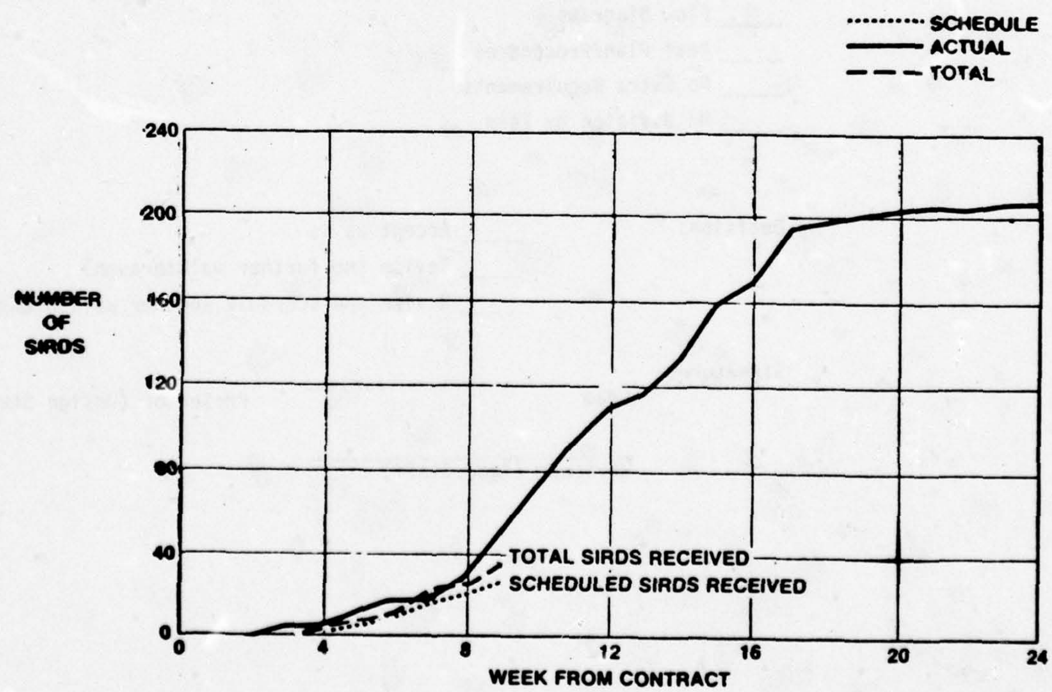

FIGURE 13b TYPICAL SIRD STATUS VISIBILITY

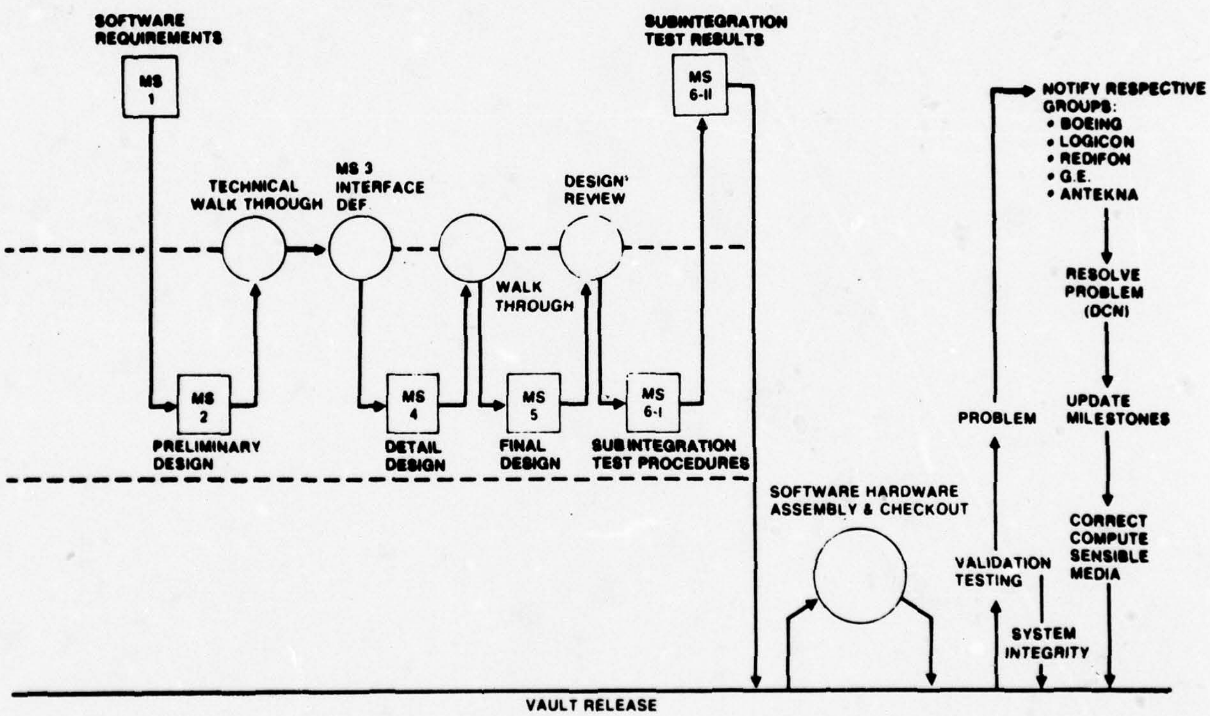

FIGURE 14 COMPUTER PROGRAM QUALITY ASSURANCE

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INFANTRY WEAPONS TRAINER

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BON F. SHAW
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and
DR. HERBERT C. TOWLE
University of Central Florida

The Infantry Weapons Trainer is an electrooptics-based, microcomputer-controlled, training device that enables tactical infantry weapons training under a simulated high-stress battlefield environment in a classroom or aboard ship. In a short period of time a trainee can be subjected to a large variety of combat situations where each trainee's performance is analyzed in real-time, and immediate feedback is given to both the trainees and instructor. Combat scenarios can be changed to fit any potential battlefield requirement. The trainer shown in Figure 1 is presently configured for a maximum of five infantry men as used by the Army; however, the Marine Corps version is for four men.

The system has two motion picture projectors: a visual and an infrared (IR) projector (see Figure 2). The visual projector displays the battle scene including visual targets. The infrared projector provides invisible infrared target areas which the weapon must be aimed at in order to score a hit. Lead is programmed into the infrared target, which the weapon receiver detects, requiring the trainee to lead the target as necessary. Figure 2 shows the visual target on the left and the infrared target on the right indicating that the target is moving to the right.

Each trainee has a simulated M-16 rifle with an attached infrared (IR) detector. The IR detector is a four-quadrant photo diode. The four-quadrant target information and microcomputer logic determine kills, eight areas of near misses, and total misses.

When the trainee fires the weapon, he hears a simulated bang and feels a recoil. Recoil is generated by a short pulse of air released near the front sight which drives the weapon high and to the right. An 8080-based microcomputer determines where the round would have hit and supplies this information to both a computer-generated voice unit and a cathode-ray tube (CRT) display on the instructor's station. The computer voice unit drives both the trainee's and instructor's headsets. When a target appears on the screen, the IR projector outputs a target present signal. This signal starts a clock in the microcomputer which measures the time until the trainee fires, for his reaction time. The target present signal is also used to determine: the number of targets that appeared, targets ignored, targets shot at and if the trainee shot when no target was present. Five trainees' results are continuously displayed in five columns on a CRT display on the instructor's

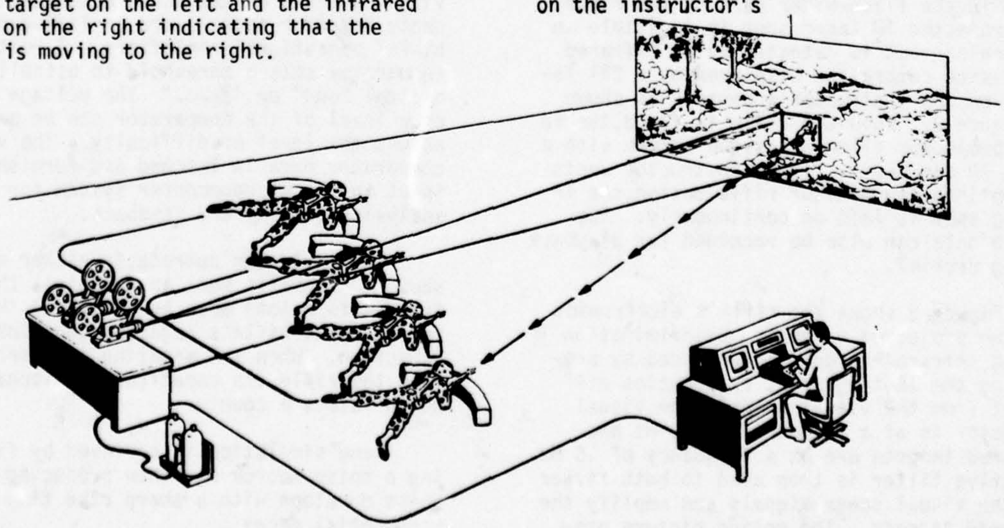

Figure 1. Artist's Concept of Infantry Weapons Trainer

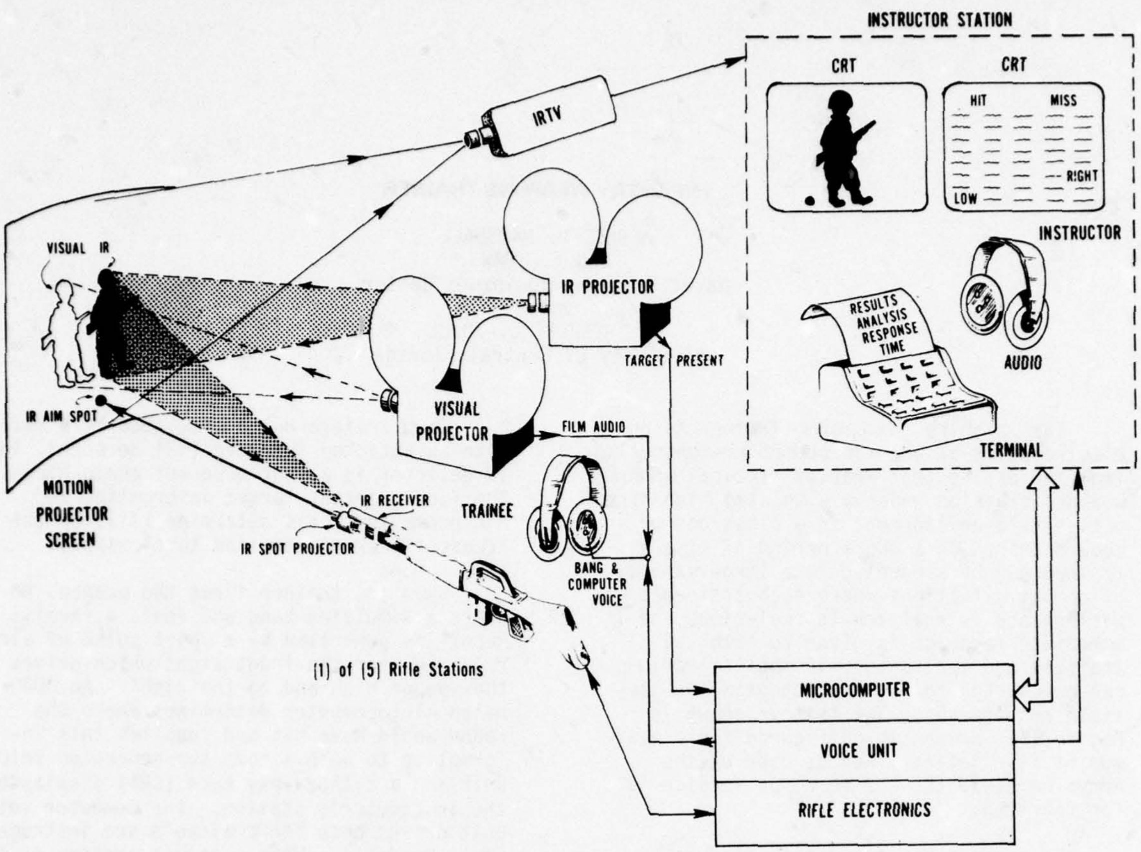

Figure 2. System Block Diagram

station. At the completion of the exercise the results, analyses and response time are printed by a terminal at the instructor's station.

Distribution of fire can be monitored using a gallium arsenide infrared source located in the flash-hider part of the rifle. The projected IR laser spot is invisible to the trainee but is detected by an infrared television camera and displayed by a CRT located on the instructor's console as shown in Figure 2. When the rifle is fired, the IR spot projector illuminates the screen with a small IR aim spot. If the instructor wants to continuously monitor rifle motion, the IR aiming spot is left on continuously. The camera data can also be recorded for playback during debrief.

Figure 3 shows the rifle's electronics and two projected targets. Discrimination of the infrared targets is enhanced by projecting the IR targets at frequencies different from the visual scene. The visual projector is at a frequency of 48 Hz and infrared targets are at a frequency of 96 Hz. An active filter is then used to both filter out the visual scene signals and amplify the infrared targets. The motion picture projectors have also been modified to incorporate optical filters. The infrared target projector displays IR data and the visual projector displays the visual targets. The rifle uses a lens and a four-quadrant photo diode detector to detect infrared targets. An infrared filter is utilized to reduce the visual signals on the photo detector. The photo detector signals are amplified by two bi-FET operational amplifiers. A voltage comparator sets a threshold to establish a digital "one" or "zero." The voltage reference level of the comparator can be set to adjust the level of difficulty. The voltage comparator data is latched and furnishes input to the microcomputer system for data analysis, display and feedback.

The rifle can operate in either a single shot or automatic mode and requires the trainee to reload when he has fired thirty rounds. The rifle's magazine contains a capacitor. When the magazine is inserted into the rifle, its capacitor is discharged which resets a counter.

Bang simulation is achieved by filtering a noise source and then producing a noise envelope with a sharp rise time and exponential decay.

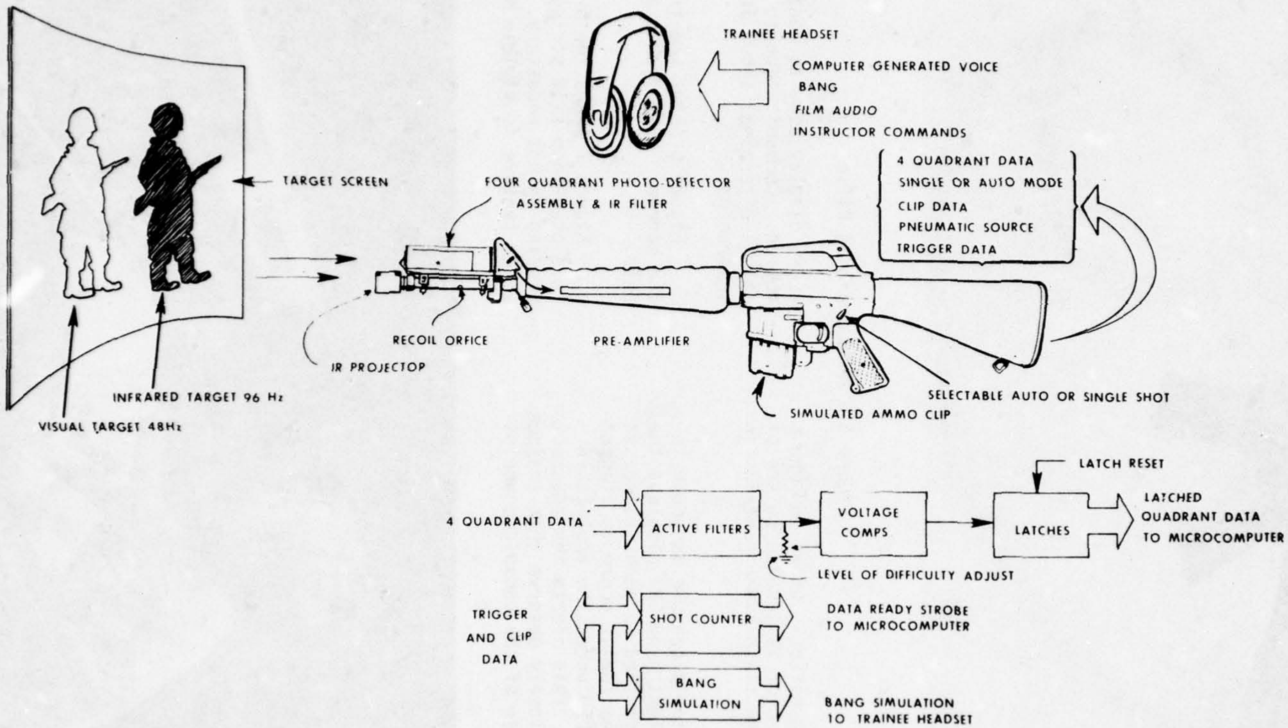

Figure 3. Rifle Electronics Block Diagram

Figure 4. M-16 Training Rifle

The training rifle is shown in Figure 4. The quadrant detector is located on top of the barrel and the flash hider contains an IR laser.

The instructor's console is shown in Figure 5. The right hand CRT displays the verbal data transmitted to each trainee in five columns. The lowest score is flagged by turning on a LED under the applicable trainees column. This alerts the instructor, so he can more closely observe that trainee. The left hand side of the console contains a CRT display used to monitor the weapons motion. Communication to the microcomputer is via a terminal shown in front of the instructor.

Figure 6 shows the trainees firing at the screen. Note each trainee wears a head set.

Figure 7 shows the projectors. Loopers (a closed-loop film strip) are used so re-winding is not necessary. An auto-stop/auto-align feature is visible near the loopers.

Figure 5. Instructor's Console

Figure 6. Trainees Firing at Screen

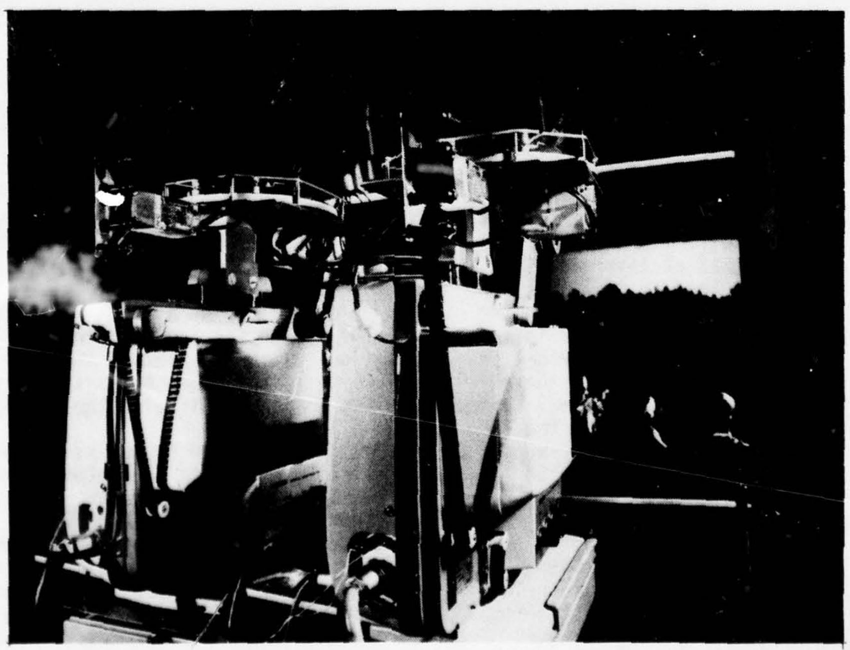

Figure 7. Synchronized Visual and IR Projectors

The computer voice system is a solid-state communications processor. It operates as a standard data terminal to the host 80/20 microcomputer system. The vocabulary has been digitized and stored in non-volatile memory (PROM). The system contains thirty-two individually addressable words and five independent output channels. Thus, the computer voice system can talk to any or all of the five trainees while saying the same or different words or phrases. Each trainee wears a head set so he hears only the feedback applicable to his performance.

The system is controlled by a modified Intel 80/20 microcomputer system, Reference 1. The microcomputer system includes an enclosure with front panel controls, power supply, cooling fans, and a card cage in which is located the main 80/20-4 board as well as the interface board (IFB). Figure 8 shows the system communication paths from the main board via the IFB. With the exception of the serial data paths to and from the console CRT, terminal and audio systems, all data are transferred through the main board parallel I/O ports 1, 2, 3 and 6.

A target present signal from the IR target projector is carried directly through the interface board to the main board through input port 2. The target present information is recorded and used during scoring to identify a valid shot.

The IR quadrant detector data are input from each rifle to a separate 8212 eight-bit input/output port chip on the IFB. A trigger-pull signal is also sent from each rifle to its associated 8212. Upon sensing a trigger signal, the quadrant data are latched into the 8212 buffer and an interrupt signal requesting service is output from the 8212 to the main board through input port 1. The service request lines from all five 8212s are "ored" together onto a single line which also goes to port 1 to signal that at least one 8212 requires service. As long as this ored line indicates a service need, the microcomputer polls each 8212 service request line in turn. When one is detected that needs service, the address of the 8212 responsible for the request is output from port 3 on the main board to a 9311 one-of-sixteen decoder on the IFB. A data read signal is then output from port 6 to the 9311, which commands the 8212 to place the contents of its latched buffer on the common data bus.

Each of the other four unaffected 8212 chips may also contain data, but are held temporarily in an inactive "three-state" and present a high impedance load to the bus. The only quadrant data available at the main board port 2, therefore, are from the 8212 being serviced. These data are read into memory and the data read signal to the 9311 is removed. This removes the read command to the 8212 and clears the interrupt service request. A pulse is then sent from port 6 to the 9311 which issues a reset signal from the IFB to the rifle associated with the serviced 8212.

The serviced 8212 is now in three state, its service request line is off and it is ready to latch in new data upon receiving the next trigger-pull signal. In the meantime, if other 8212 chips need service, the process is repeated, if not, the next 8212 service line is polled in sequence. This continues until the ored service line goes off and the computer moves ahead with the remainder of the program.

The instructor is kept informed of the session's progress in three ways: (1) from a console CRT where shot scores for each trainee are constantly updated, (2) by audio comments from the digitized word system, and (3) by observing rifle movement and distribution of fire using the IR TV display. The instructor may choose to monitor a trainee by selecting one of the five trainees audio output channels. The CRT screen channel is fast enough to allow all shot results of all trainees to be presented. Both of these information sources originate from the IFB high-speed serial data outputs. The "baud rate" of these data streams is 19,200 bits per second as compared with 110 bits per second used for the usual teletypewriter (TTY) communication. Such high-serial data rates are required to keep up with simultaneous automatic fire from five trainees.

The control terminal may be either a TTY with a baud rate of 110 or a terminal operating at a rate of 300 bits per second. At the beginning of each training session, the computer connects the output serial data stream from the 8251 programmable communication interface or universal synchronous/asynchronous receiver/transmitter (USART) to the terminal. Because input USART data are always available from the terminal, the computer is able to carry on a two-way conversation with the instructor in order to obtain "initialization" data. As shown in Figure 9, the computer questions the instructor and prompts for answers by issuing the character ">."

During the actual training session, audio system data are output from the USART, while console CRT data are output in parallel from port 6 to an 8741 universal peripheral interface 8-bit microcomputer (UPI-41) on the IFB. The UPI-41 translates the parallel word into the proper score for the shooting rifle, and outputs rifle number and the score as a serial data stream to the CRT screen on the instructor's console.

When the session is finished, the instructor strikes any key on his terminal

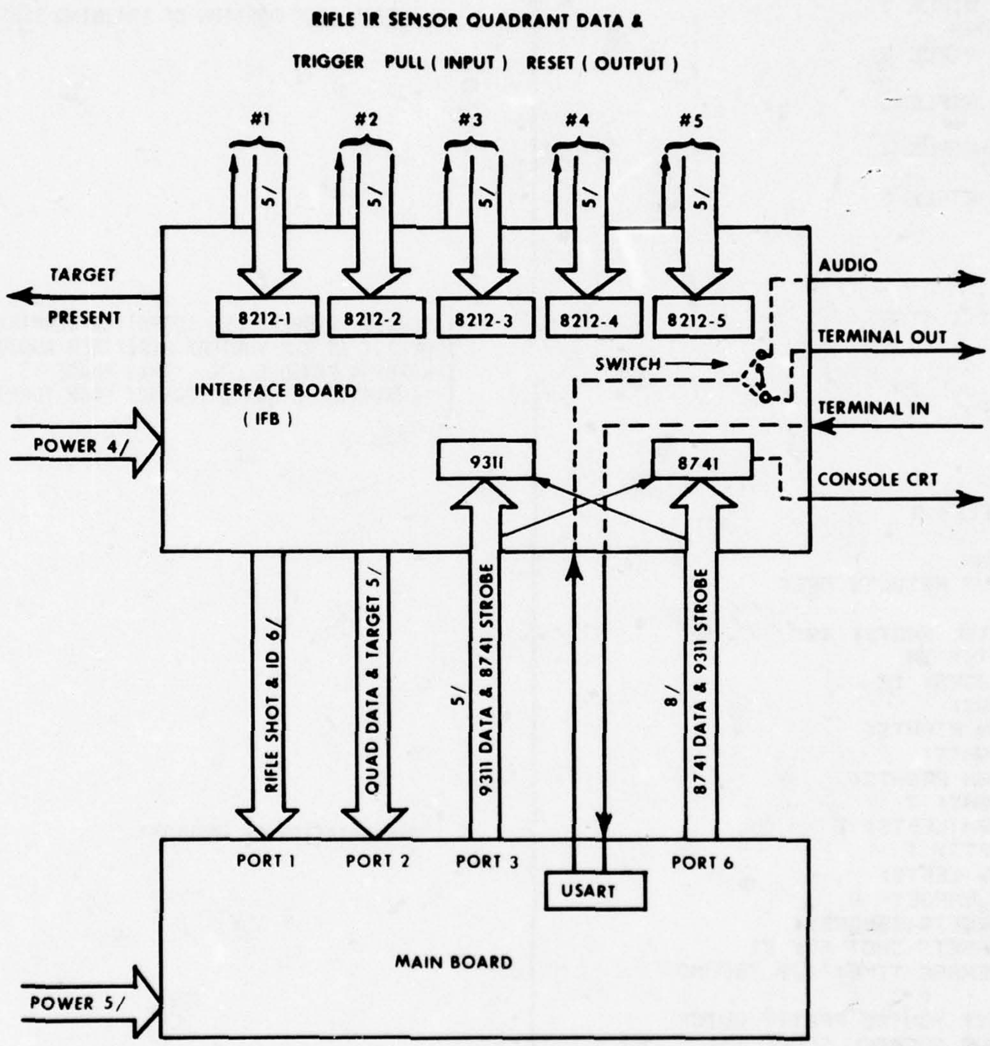

Figure 8. 80/20-4 Main & Interface Boards

```
UIWT/SWAT VER. 1.3

WANT ID? YES OR NO.
Y
TODAY'S DATE?
>13 JUL 79
EXERCISE NUMBER?
>0002
ENTER NAMES OF TRAINEES
ON RIFLE 1
>JOHN
ON RIFLE 2
>
ON RIFLE 3
>
ON RIFLE 4
>
ON RIFLE 5
>


LET'S START
```

"INITIALIZE" PORTION OF TRAINING SESSION

SESSION PROPER. NO OUTPUT TO TERMINAL. OUTPUT IS VIA VORTRAX DIGITIZED AUDIO WORDS & CONSOLE CRT. THIS PHASE IS TERMINATED BY AN INTERRUPT FROM TERMINAL.

```
13 JUL 79
0002


RIFLE: 1

JOHN
YOUR RESULTS ARE:

TOTAL SHOTS: 49
HITS: 14
MISSES: 12
LOWS:
LOW RIGHTS:
RIGHTS:
HIGH RIGHTS:
HIGHS: 7
HIGH LEFTS: 7
LEFTS: 1
LOW LEFTS:
NO TARGET: 8
TARGETS IGNORED:
TARGETS SHOT AT: 21
AVERAGE TIME: 0.9 SECONDS

HEY! YOU'RE PRETTY QUICK
YOUR OVERALL SCORE IS:     66
```

"PRESENTATION OF RESULTS"

TYPICAL FORMAT ON TERMINAL CONTINUES FOR ALL FIVE RIFLES.

Figure 9. Sample Computer Printout Presenting Initialization and Results

and USART output is again directed to the terminal which types out hard copy scores, as shown in Figure 9.

Operation of the 80/20-4 microcomputer is directed by a sequence of commands in fixed program memory, i.e., read only memory (ROM), while program variables are stored in read/write memory, i.e., random access memory (RAM).

ROMS are programmed by copying a sequence of machine command words into sequential memory locations from an appropriate external file. In general, this file of machine command words may result from the translation of any assembly or higher level language. The machine code was compiled from a program written in PL/M-80 language which is similar to the PL-1 language. Reference 2 gives a number of PL/M-80 examples, while Reference 3 provides the language syntax and other definitions.

The overall program strategy is shown in Figure 10 after power has been turned on. The program starts when the 80/20-4 "reset" button is pushed.

During "initialize" the program issues a series of questions to the system console and prompts for answers. If desired, the date, training session number, and trainee names are obtained and stored for future reference, as shown for the "initialize" portion of the training session of Figure 9. When all identification data have been collected and other housekeeping details completed, the program issues "let's start" and the main training session loop is entered. This loop may be executed along the three different paths indicated on the flow chart.

If there is no target present on the screen and no rifle trigger is pulled; i.e., no "action," the path 3 will be selected by program logic. No data comments are generated during early passes around the path 3 loop. Subsequent "action" will cause flags to be set and a return to path 3 may result in a comment of either "no target" or "you froze" being sent to the earphones of any erring trainee. Corresponding error data are filed for the identified trainee which will lower his score presented on hard copy after the session ends.

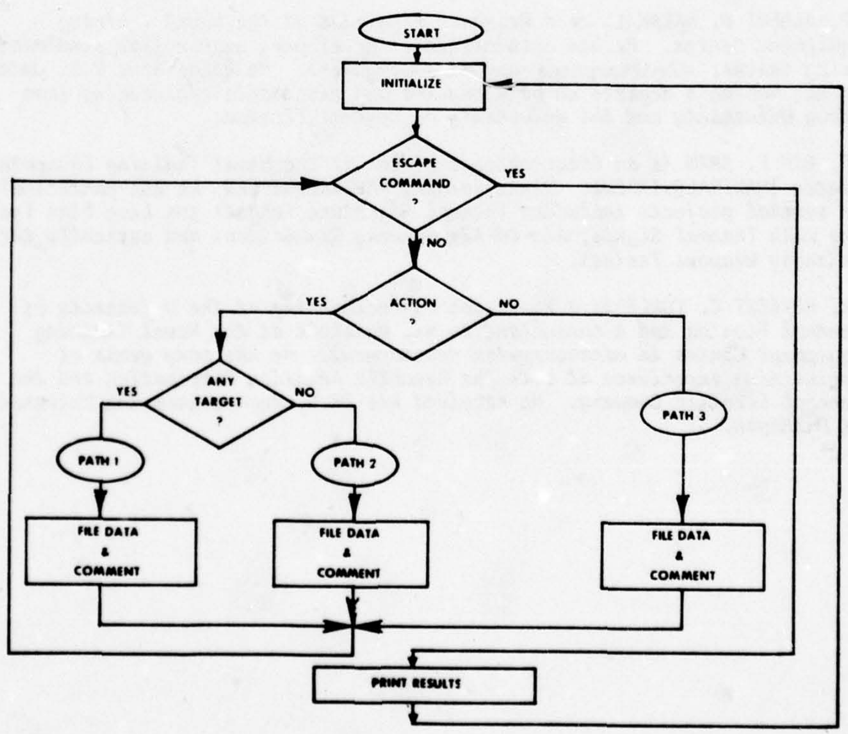

Figure 10. Program Strategy

"Action" is true after a target becomes available and/or rifle is "fired." The session loop will now pass through either path 1 or 2 as dictated by program logic. This logic also determines the proper data to be filed and comment to be sent to the trainee's earphones. For example, if the target disappears but the trainee persists in shooting for more than one second, then a "no target" comment will be sent to the rifleman, and a negative score is placed in his data file.

Operation remains locked in the session loop until an escape is signaled by the instructor pushing a console key. This causes a system interrupt and control passes to "print results" which produces output as shown in Figure 9. The program then returns to the "initialize" block and data records are initialized in preparation for the next training session.

A set of training sessions is terminated upon the instructor's turning off system power. The microcomputer system includes self-check features which allow tests to be made of all fixed and variable memory, input/output paths as well as the elapsed time clock.

The system has been developed and a prototype produced and tested. Advanced models are now undergoing testing by both the U. S. Marine Corps and the U.S. Army.

REFERENCES

1. "System 80/20-4 Microcomputer Hardware Reference Manual," Intel Order Number: 980484A, Intel Corporation, Santa Clara, 1977.

2. D.D. McCracken, "A Guide to PL/M Programming for Microcomputer Applications," Addison-Wesley Publishing Company, Reading, Mass, 1978.

3. "PL/M-80 Programming Manual," Intel Document Number 98-268, Intel Corporation, Santa Clara, 1976.

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KEEPING DOWN THE COST OF TRAINING: A CHALLENGE TO THE USER

ALEXANDRA B. TAYLOR
The Singer Company - Link Division

THE NEED FOR CHANGE

Simulator users, in particular the military, are facing restrictive procurement budgets as well as rapidly increasing maintenance costs for existing simulators. The simulator industry would like to meet the challenge of keeping down both the acquisition cost and support cost of future training devices. Industry attempts to limit procurement costs by utilizing designs and software developed on previous programs. At the same time, industry attempts to develop and offer new designs in areas which yield a significant decrease in the cost of the ownership. At times, however, industry is constrained by a Request for Proposal (RFP) that specifies detailed design rather than performance objectives. These design specifications often have serious cost impacts. Detailed design specifications can be replaced by functional specifications which will allow industry maximum design creativity while giving the user a more cost-effective training device.

Government sensitivity to the cost impact of detailed design specifications is reflected in Office of Management and Budget (OMB) Circular A-109, Major Systems Acquisitions. OMB A-109 recommends defining system or training objectives rather than specifying detailed system design and performance requirements. OMB A-109 emphasizes the definition of mission needs and program objectives independently of a particular system or technological solution in order to stimulate innovation and competition. By writing a functional procurement specification, industry will be encouraged to create, explore, and develop alternative system design concepts.

NEW CONCEPTS FOR PROCUREMENT

In response to the spirit and challenge of OMB A-109, new approaches to procurement practices have been applied during the past few years. Although some of these approaches may, in reality, predate A-109, they are, nonetheless, valuable techniques which can be used to obtain the ultimate goal - a more cost-effective training device.

One approach which can encourage industry competition and creativity is the funding of multiple concept studies. In the early stages of the AH-64 Advanced Attack Helicopter (AAH) program, three separate study contracts were awarded. The purpose of the concept formulation study was to determine the technical feasibility, economic considerations, and the best technical approach for a Flight and Weapons Simulator to be used in support of an AAH training program. These multiple concept studies provided the procuring agency with several approaches to use as a basis for capability trade-offs when developing the final procurement package.

Another technique to be employed in the acquisition cycle is the draft specification. In this process, the procuring agency develops a preliminary specification and submits copies to industry for review and comment. Each reviewer is usually asked to identify items of the specification which are considered to be unduly restrictive or may have high cost impact. Included in the process is the opportunity for each potential contractor to discuss the comments with the procuring agency. The draft specification cycle has been used on a number of recent procurements, including the C-130 Visual, the Flight/Attack Simulator Visual System (F/ASVS), and the AAH Combat Mission Simulator. Comparative analysis of the draft specifications can yield many insights for the procuring agency as well as the potential contractor. The procuring agency can expect to receive worthwhile comments only if industry believes that their comments will be carefully evaluated before the specification is finalized. Since the draft specification gives industry an early definition of system requirements, the draft specification process can also be an effective way to initiate industry competition at the conceptual design level. This preview gives industry research time to identify alternate system approaches and conduct trade-offs before the final RFP package is received.

Industry competition and innovation can also be stimulated by the active solicitation of alternate proposals. During the procurement of the Visual Technology Flight Simulator (VTFS) Singer-Link submitted a basic proposal as well as an

alternate proposal. The alternate approach offered an experimenter/operator station and experimental features based on the system previously developed for the Advanced Simulator for Undergraduate Pilot Training (ASUPT). The alternate approach provided essentially all of the required system capabilities, although it differed in implementation details due to the fact that the ASUPT system had been designed to meet another specification. Since the alternate approach offered the essential system performance as well as significant cost savings, the alternate approach was selected. Alternate proposals can be a viable technique for obtaining more cost-effective training devices if they are seriously encouraged by the various procuring agencies.

Another method for implementing the objectives of OMB A-109 is the awarding of fly-off development contracts. This method maintains competition through the full-scale development phase with subsequent production award based on capability and cost of ownership demonstrated via the prototypes. The fly-off approach is well-suited to high dollar value programs such as the B-52/KC-135 Weapon System Trainer (WST). On this procurement the Simulator System Program Office (SSPO) awarded two contracts for development of a pilot production unit. Each contractor, although working to a basic specification, was required to consider, submit, and implement design trade-offs based on performance, training capability, and life-cycle cost. The incorporation of trade-offs enabled the initial simulator design to evolve into a more effective training device. The fly-off of the prototypes will allow the procuring agency to evaluate actual equipment rather than a theoretical design.

The most effective approach to stimulating design creativity is the functional specification. A functional specification identifies only the basic requirements for the desired training device. It removes design restrictions and limits. It defines the required capabilities in terms of system performance and training objectives.

One system is currently being procured using both the competitive fly-off and performance specification recommendations of OMB A-109 - the Fighter/Attack Simulator Visual System (F/ASVS). The F/ASVS performance specification contains some basic requirements and several challenging goals in lieu of a detailed system specification. The specification also offers an equally challenging production unit cost goal. This program provides maximum freedom to the competing companies in designing a system which meets these goals.

USING THE FUNCTIONAL SPECIFICATION

In developing a functional specification every aspect of the training device procurement must be analyzed. These examples indicate how selected simulator systems can benefit from less restrictive specifications.

Computational system specifications can limit design choices. Rapid progress in microprocessor technology makes microprocessors serious candidates for highly repetitive simulator computations like motion system calculations. Specifications that require only identical or upwardly compatible general purpose processors rule out use of microprocessors or floating point processors. Specifying iteration rates before system interrelationships have been established can impact computer system size and, therefore, cost.

Certain specification requirements restrict the full use of the capabilities of modern computers; e.g., restricting overlays to data and frame balancing requirements. The use of overlays in applications like performance evaluation in no way impacts the level of fidelity of the simulation and permits the computer complex to be configured in a more cost-effective manner. Specification details can affect computer system efficiency. Details of computer peripherals, like line printer and card reader speed, should be left to the simulator manufacturer who could then select units which best match the system capabilities.

At the instructor station the CRTs for instructor display and control are sometimes specified by parameters which have no bearing on the training task or operational utility. At times, CRTs are specified which are almost obsolete. Selection of CRTs should be left to simulator engineers who have daily contact with the equipment and its application. They are aware of hardware and interface problems arising both during the test cycle and in the field. In developing applications software, the engineers can judge the compatibility of a particular CRT system. They recognize the unique demands placed on CRTs as part of a simulator complex. The specification should identify a basic requirement for a display system as the method of instructor interface with the simulator and leave the choice of CRT type and configuration to the simulator manufacturer.

Voice recording systems are often required for record/playback, GCA, et. al. Specifying implementation details can have an adverse effect on LCC. Specifications have required tape systems, whereas field experience has indicated that multi-tape systems can be a maintenance nightmare. Leaving implementation details out of specifications permits industry to suggest alternate approaches like digital voice.

Specifications requiring use of government furnished equipment (GFE) in the simulator can impact cost-effective choice.

Simulator equipment operates in a controlled environment and does not require the same protection as its aircraft counterpart. The high reliability of simulated hardware must be weighed against the procurement cost, spares availability, and maintainability of aircraft hardware.

In the case of sophisticated aircraft hardware a comprehensive trade study is required before the choice between GFE or an alternate approach can be finalized. For example, in implementing an onboard computer, there are several approaches to consider: stimulation of actual hardware, simulation, emulation, and translation. Other factors, such as procurement cost, quantity required, and anticipated frequency of updates must also be considered. In addition, the role of the simulator as a training device places its own unique requirements on aircraft equipment. For example, an aircraft onboard computer is not required to function in a playback mode or in a slow-time demonstration mode. Implementation of these training featues demands certain control capabilities over an onboard computer for functions like freeze and initialization. Therefore, additional factors in the trade-off study should be the interface simplicity and control capabilities between the onboard computer and the simulation computer.

Use of commercial parts offers the potential of significant cost savings if requirements for military documentation can be relaxed. On one prototype simulator a Radio Shack intercomm was purchased for $150 as a maintenance intercomm. It functioned well. For the production units, the intercomm requirements included the applicable mil specs for drawings and wiring diagrams. The cost for an intercom which permits the same functions is now $150,000. The need for such detailed drawings and schematics should be carefully examined by the procuring agencies, especially if contractor maintenance is contemplated. Experienced personnel do not require that level of documentation in order to maintain the simulator.

Current specifications require high fidelity simulation of aircraft performance to ensure high transfer of training. High fidelity is expensive. More research is essential to determine the level of fidelity required to efficiently train aircrews. Results of research can be translated into more functional specifications.

VALUE OF FUNCTIONAL SPECIFICATIONS

Functional specifications offer both advantages and disadvantages to all involved user, procuring agency, and simulator manufacturer. By emphasizing system capabilities and training tasks, functional specifications keep industry focused on the user's goal - the efficient training of aircrews. But, in order to utilize this advantage, the user must become more involved in the generation of the specification to ensure it includes a clear and detailed definition of the task to be trained with the device. In addition, the user must maintain his involvement throughout the entire device development process.

Functional specifications are easier for the procuring agency to write, but the responding proposals are more difficult to evaluate. The design approaches presented in the proposal will probably show significant differences, thereby making comparisons and final selection much more of a judgmental process. The procuring agency will need to develop an evaluation procedure that minimizes subjective decisions. A procedure which facilitates discussion of the adequacy of the proposed approach must also be part of the evaluation process.

In responding to functional specifications the simulator manufacturer has several advantages. Existing designs and equipment can be used or adapted to meet performance requirements, thereby lowering acquisition costs. Functional specifications also give the simulator manufacturer the freedom to use new approaches which make positive contributions to LCC. Engineers, the intangible in the acquisition cycle, are also affected by functional specifications. The engineers formulate the design approaches in response to the RFP, but do not feel challenged when every switch and knob is defined in the specification. A functional specification stimulates enthusiam and creativity, resulting in increased quality. This same enthusiasm carries over to actual design efforts on a contract using a functional specification, to the benefit of both the user and the procuring agency.

On the minus side, the simulator manufacturer may find it more difficult to write acceptance test procedures (ATP) for a device procured with a functional specification. However, if current practices are retained, the contractor generates a more detailed specification during development of the training device. This detailed specification is then used as the basis for writing the ATP.

The advantages offered by functional specificatons to all involved are compelling. Functional specifications can make a significant contribution towards holding down procurement and ownership costs for new training devices. The challenge to the user/procuring agency is simple - make specifications more functional. Give every part of a specification careful scrutiny - frequently. Continue to use the draft specification cycle and get industry involved early. The end result, a good functional specification, will then return the challenge to industry. Industry will be forced to focus on training requirements and respond with more efficient and cost-effective training devices.

REFERENCES

Markwood, Colonel Calvin H.. "USAF Simulator Fly-Offs Via A-109" Military Electronics/Countermeasures. October 1978

Office of Management and Budget Circular No. A-109, "Major Systems Acquisitons".

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ADVANCED INSTRUCTIONAL CONCEPTS IN FLYING TRAINING SIMULATION

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NOTE: The following material is the script portion of a sound/slide presentation entitled "Advanced Instructional Concepts in Flying Training Simulation." The presentation is unclassified, and is available upon request from AFHRL/FT, Williams Air Force Base, Arizona 85224.

Economic and resource constraints demand more cost-effective approaches to routine training needs. The impact of these constraints upon the Air Force is seen in the increased use of simulators at all levels of flying training.

While simulators offer the promise of greater training efficiencies, their primary importance lies not in the number of flying hours saved, but in their potential for achieving an increased level of combat readiness. Evidence already exists to show that the efficient use of simulators can bring about significant reductions in the physical resources necessary to accomplish routine training.

The real challenges in the years to come lie in developing simulators as training devices that are able to overcome the limitations and constraints of a real world training environment. No longer is it sufficient to work simply toward the development of high fidelity replicas of the aircraft we operate. The truly important task is the effective simulation of the tactical environment in which these aircraft are employed.

A legitimate concern exists over the extent to which instructional methods associated with the use of actual aircraft as training devices provide the most effective techniques for conducting training in simulators. While these methods are obviously valid for teaching persons to fly, they fail to capitalize upon the unique instructional capabilities of the simulator as a training device. It is this unique instructional capability that this presentation is all about.

Flight training simulators of the next decade are likely to contain provision for numerous instructional support features such as In-Flight Condition Store, Freeze, Rapid Reinitialization, and Record/Playback. Despite the presumed effectiveness of these features, little or no guidance exists as to their operational use . . . especially those applications which do not follow directly from use of the simulator as a "substitute" aircraft.

This research represents the beginning of an effort by the Flying Training Division of the Air Force Human Resources Laboratory to collect data upon which to base such guidance. The research approach involves studying the effects of a variety of instructional variables as measured by performance on representative "benchmark" tasks. Among the tasks which have been considered are carrier landings, aerial refueling and air-to-surface weapons delivery.

Considerations involved in the selection of the tasks are that they be discrete . . . capable of being acquired in a single simulator session . . . conducive to objective performance measurement . . . and above all, that they can be of operational significance to the user.

With one exception, instructor pilots assigned to Williams AFB have served as subjects. In these instances, the task selected for study has been an air-to-surface weapons delivery task. Training has been conducted in the T-37 configuration of the Advanced Simulator for Pilot Training. The one exception to the use of instructor pilots as subjects has been in the investigation of the Record/Playback feature, where Undergraduate Pilot Training students served as subjects in the acquisition of an aerobatic maneuver.

In one of the first studies to be completed, a continuously computed impact point cue was evaluated as an aid in the acquisition of a manual dive bombing task. The cue consisted of a spot of light which appeared to the pilot to move along the ground, indicating the point of impact for a bomb dropped at that moment. It was hypothesized that the addition of such a predictor cue to what is essentially a complex tracking task would reduce the number of trials required to learn the task. Although this was not found to be the case, the results of the study contained important implications for pilots' use of similar information when programmed as part of a head-up display.

In a second series of studies, the simulator's capability for establishing multiple initialization conditions was used to arrange for a backward chaining approach to the 30-degree dive bomb task. Under backward chaining, the last response in a response chain is acquired first. Learning then proceeds "backward" in the chain until all members of the chain are acquired. Outside of unpublished references to the Navy's use of a similar approach for teaching night carrier landings, no precedent for the use of backward chaining existed in the published flying training literature.

The results of the study showed that when training time for the two alternative methods was equated, pilots' accuracy under the backward chaining approach was significantly better than the accuracy of pilots who learned the task under a traditional whole-task approach. For example, in the time required for seven of ten pilots in the backward chaining group to reach criterion, only three of ten pilots under the whole task approach had done so. The findings are significant not only in that they have immediate training application, but that they support the utility of recognized, learning theory principles and techniques for flying training simulation.

One of the most widely recognized learning theory principles is that of immediate feedback. According to the principle, learning is facilitated when feedback is made to immediately follow a response. An attempt was made to evaluate the significance of this principle for the acquisition of a task such as the dive bombing task.

Pilots acquired the "final leg" component of a 30-degree dive bombing task under conditions where the feedback delay normally experienced between the time the bomb is released and the time the bomb strikes the ground was eliminated. Since the calculation of bomb impact is performed instantaneously in the simulator, such a condition is easily arranged for in the simulator by eliminating the delay portion of the program.

In addition to the use of immediate feedback, the capability for resetting the simulator back to the exact conditions occuring at the time of release was arranged through use of the systems in-flight condition store feature. The task thus became one where the pilot released the bomb . . . . received immediate feedback as to its point of impact . . . . pulled off, and following a return to a wings level attitude was reset to the exact conditions at the time of release.

Through the joint use of immediate feedback and freeze, a significant reduction in the number of trials needed to acquire this portion of the overall task was achieved. Research is continuing to improve the efficiency of simulator approaches for teaching this and other flying performances consisting of response chains.

In a recently completed study, Undergraduate Pilot Training students acquired a complex, visual-motor flying task. The experimental task was the first two leaves of a clover leaf maneuver. The study compared periodic use of a performance playback with the use of an equivalent amount of training time for additional student practice. The results were interesting in that by the end of training, the group who had received the replays were performing no better than the "practice only" control group. The implication of these findings is that at least for some tasks, the provision for simple knowledge of results may be equally as effective as the provision for the replay of student performance.

In addition to the studies just described, work is also proceeding which is aimed at developing the capabilities of other less well recognized features of the Advanced Simulator for Pilot Training. One such feature is the General Electric Video Insetter.

The insetter provides the capability for inputting alphanumeric and graphic displays into a computer-generated visual scene. The capability is provided through use of a repeater graphics display, video camera, and visual processing unit. Displays available to the instructor at the instructor/operator console can now be presented to the pilot without modification or alteration of the interior of the cockpit. Such a display can be static as in the case where the insetter is used to generate a display of bomb impact points and release parameters or dynamic, as in the case of depicting glidepath and centerline deviation.

The significance of the video insetter is that it allows for the projection of objects into the pilot's visual scene without such objects having to be preprogrammed as part of the computer-generated visual data base. In doing so, it provides an "overlay" capability that might be used to "point out" the locations of objects in the visual scene. One might even envision the insetter as eventually providing an instructor, armed with a light pen, the capability for immediate and selective interaction with the pilot's visual environment.

The research which has been presented thus far has dealt with the development of training applications for instructional capabilities that currently exist on the Advanced Simulator for Pilot Training. One such capability is that for conducting formation flight. Consider the full range of possibilities associated with this training feature.

One of several ways of arranging for the conduct of formation flight is through the use of two separate cockpits, each flying interactively with the other through the presentation to each of a computer-generated image of the second aircraft. Two independent eyepoints are thus provided. Think now of what else this might allow one to accomplish.

First, consider a carrier landing and the two primary participants involved in a simulation of that task: the pilot of the aircraft performing the landing and the Landing Signal Officer or "LSO." The LSO is an individual positioned toward the end of the carrier's flight deck who communicates to the aircraft instructions for accomplishing a sucessful recovery. The two "eye points" are (1) the pilot's eye point, and (2) the eye point of the LSO.

The same capability that provides for the simulation of formation flight can also satisfy this requirement by having one "cockpit" provide for the simulation of the aircraft and the other provide for the simulation of the LSO's visual environment. Simulation for the LSO is in principle no different than simulation for a second aircraft flying in formation. The only difference is the eyepoint of the second participant . . . in this case, the LSO located in a static position on the flight deck.

Now to develop the concept one step further. If the second cockpit can be used to provide a simulation of the LSO's visual environment as seen from the flight deck of a carrier, then there exists no inherent reason why it could not also be used to provide a simulation of a weapon system located at ground level. All that would be required for such a simulation would be the provision for some type of sighting device and tracking apparatus. For the case of the A-10, the ground weapon system might provide for an enemy anti-aircraft site or surface-to-air missile site.

Such a simulation would provide the A-10 not only with a live interactive threat, but would also provide a playback capability where the A-10 could receive feedback as to the target that it presents to the ground weapon system. Such a capability would also lend itself to the development and evaluation of new and existing tactics for the A-10 in the ground attack role. Given that the primary mission of the A-10 is that of close ground support, an ideal tactical target would be a tank.

Currently, the US Army Armor School at Ft Knox, Kentucky is developing a full-crew interaction simulator for a tank weapon system. It is believed that the simulator is to employ a computer-generated visual data base, at least in some respects like that used with the Advanced Simulator for Pilot Training. It is also known that the tank simulator is to be capable of visual modeling of the same Central European environment in which the A-10 is to be operationally deployed.

By linking together an A-10 simulator and a tank simulator such as that being developed at Ft Knox, tactical scenarios like those envisioned for Central Europe could be conducted. Not only could integrated tactics employing A-10s and tanks against an armor threat be developed and evaluated, but A-10s could gain experience against tank type targets operated by live aggressor crews.

While the concept being developed here may sound futuristic, in principle it is identical to the situation presently possible in ASPT where two cockpits are flown interactively, with each presenting to the other, a computer-generated image of itself, the present example simply deals with the simulation of dissimilar weapon systems and extends the geographical distance between simulators. Given compatible visual data bases and the capability for establishing the physical link between systems, the concept is certainly within current state-of-the-art for training simulation.

The possibilities for broad range tactical simulation should now be apparent. Imagine the following scenario. At some predetermined time, members of A-10 squadrons located at different simulated airfields around the country become airborne and proceed together in tactical formation over common computer-generated terrain to some designated point. At the same time, naval air support is launched from carrier simulations. Before rendezvousing, naval and air force aircraft each conduct aerial refueling enroute. As A-10 and Naval aircraft proceed in formation to their target, aggressor aircraft flown from

Tactical Air Command simulator facilities engage the attack force. Once the target area is reached, a coordinated attack is launched against a simulated armor threat operated under the control of simulator aggressor crews at the Armor Center at Ft Knox.

Development of the concepts discussed above follow logically from an extension of ASPT's present capability for conducting formation flight. From that capability, it was discussed how a second cockpit could be used to provide a tactically different eyepoint. Consideration was then given to utilizing the second eyepoint as a ground weapon system (for example, a tank). Given that Ft Knox is currently developing a tank simulator with computer-generated visual data base, thought was given to accomplishing a physical link between the Ft Knox tank simulator and a flight simulator such as the A-10. Further thought was given to extending the link to include simulated carrier based aircraft and simulated aggressor aircraft.

This briefing has provided an overview of work done within the past year toward the operational employment of a flight simulator's advanced instructional features. While individual studies have emphasized the investigation of variables involved in the effective use of selected features, concepts which truly exercise the limits of the present state-of-the-art are also being pursued. Work to be conducted in the near future will continue these efforts both within the context of the A-10 and the soon to be developed F-16 flight simulator.

This presentation was prepared by the Flying Training Division of the Air Force Human Resources Laboratory, Williams Air Force Base, Arizona under work unit 1123-02-34 entitled Advanced Instructional Features and Methods in ASPT. The work unit supports Project 1123, Flying Training Development; Task 02, Instructional Innovations in Flying Training. These efforts further support AFHRL Planning Objective G03, Specific Goal 2, Training Methods and Media.
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THE INFLUENCE OF FULL-MISSION SIMULATION ON VISUAL SYSTEM CAPABILITY

LT. COL. MANFRED HAAS and MR. PETER GULDENPFENNIG

In evaluating the prototype full-mission simulator for Western Germany's multi-role combat aircraft, the PANAVIA TORNADO, important experience was gained in determining the degree of quality demanded of the visual system by this type of simulator.

The role of the TORNADO as the principal battlefield interdiction and strike aircraft for the West German military required pilots to maintain a high degree of combat readiness for a multitude of tactical situations. Four Air Force and two Navy wings should be operational by 1985 and the overall program calls for each wing to be equipped with a full-mission simulator capable of performing a degree of realism never achieved before in simulation within the German Air Force. The simulators are to be delivered progressively over a 3½-year period starting in 1981.

Decisive consideration of the TORNADO training program took place during 1975. At that time, state-of-the-art technology in motion systems, digital radar landmass simulation and, in particular, computer-generated visual image systems (CGVIS) indicated that a full-mission simulator was both technically and economically feasible.

A major condition of the TORNADO training program was to develop, integrate and evaluate the CGVIS in prototype form before committing to a definitive technical specification.

The original visual system module had the following performance characteristics:

A. GENERAL CHARACTERISTICS

1. Number of channels - 3

2. Real-time scene capacity (i.e., portion of the on-line data base processable at a given time) - 2000 edges and 1000 point light sources. This represented a total capacity and was shared between 3 channels.

3. On-line data base - 10,000 edges and a minimum of 1000 point light sources.

4. View plane elements - Standard United States video of 525 lines with 2.1 interlace. Of these, 470 lines and 500 elements/lines per display were visible to the trainee.

5. Levels of detail - 8

6. Frame rate - 30/second

7. Color capability - 63 colors, selectable from 16,000,000 hues.

8. Smoothing - Smoothing of discrete raster element steps was provided in the horizontal and vertical direction. This was also applicable to point light sources.

9. The visual system responded to an output from flight simulator interface within 100 milliseconds.

B. SPECIAL EFFECTS

1. Moving targets - The capability was provided to display up to three moving targets at any one time. These were ground/sea targets, air targets and others. These targets were provided within the real-time edge and point light capacity of the system.

2. TV Missile Simulation - In lieu of normal pilot display, a scene representative of that generated by a TV missile camera was generated from the on-line data base for the navigator's display. The scene was unchanged in its timing relationship from that employed in the visual system. The image generator computed the scene with the TV/TAB system from the computed location and orientation of the missile. During this phase of operation, the visual system was required to provide an out-the-window presentation to the student pilot.

3. Special Lighting Effects - Strobe lights, directional lighting such as visual approach slope indicator (VASI), airfield, runway, taxi and approach lights to CAT-II standards and beacon and flashing lights, were simulated in accordance with data base definitions. Lights having recognizable shape or size were made up from edges.

4. Haze and fog - Simulation of runway visual range, fading and cloud base were provided, with the parameters variable under instructor control.

5. Clouds - Cloud base and thickness under instructor control was variable off-line. When the simulated aircraft was not in an area covered by a data base, the effect was "as if flying in a cloud."

C. DISPLAY CHARACTERISTICS

Field of view - The total field of view 26° (vertical) by 106° (horizontal) divided

into three channels and was designed to fit a maximum amount of the windscreen of the simulated multi-role combat aircraft (MRCA).

2. Contrast ratio - 20:1 minimum

3. Head motion - $\pm$ 2 inches (horizontally and vertically)

4. Highlight brightness - minimum of 6 foot-lamberts

5. Display distortion - less than 2%

6. Convergency - The optical system provided a virtual image wherein the rays appeared to converge at a distance greater than 20 meters.

In 1978, this prototype was evaluated by German Naval and Air Force pilots working with program personnel from Messerschmitt-Bolkow-Blohm and representatives from the Technical Directorate of the German Air Force. In performing the evaluation, the pilots exercised the simulator in situations which corresponded with the range of operational maneuvers foreseen for the TORNADO. These situations included:

1. Takeoff and landing

2. En route flight including terrain following

3. Ground and sea attack

4. Navigational updates using head-up display

5. Final phase of air-to-air combat

6. In-flight refueling

7. Formation flying

8. Threat from missile sites

9. Bombing runs

For this purpose, the following data bases were created:

1. Standard air-to-ground range

2. Tactical air-to-ground range (SAM site)

3. Navigational area (Altmuehl Valley)

4. Other aircraft

5. Moving targets on the ground (tanks)

For all missions, adequate scene detail was required in respect to:

1. Position cues

2. Motion cues

3. Object and event recognition

In general, the efficiency of the full-mission simulator concept was proven by the results of the prototype evaluation even though not all parameters of the visual system were fully adequate for all missions.

In respect to the required training tasks, the evaluation showed the following results:

1. Takeoff and landing. This required a presentation of the airport, taxi markings and lighting system by the CGVIS.

a. Taxi - Aircraft on the ground, moved on taxiway and runway to the "hold" markings.

b. Takeoff - Aircraft moved down the runway, accelerated, took off and gained height. Runway markings and the lighting system had to be observed at close distance. The dynamic impression during acceleration would be improved by a detailed presentation of the surroundings of the runway (different colors, buildings, etc.). The actual airport was, therefore, modelled in a high level of detail. The surroundings of the airport (10 x 10 km)were modelled in a lower level of detail. The rest of the whole data base (200 x 200 nm) was modelled in a very low level of detail. This was necessary due to the limitation of the real-time data base (10,000 edges).

c. Approach and landing - same requirements apply as for taxi and takeoff. The lighting system presented by the CGIVS was in accordance with Stanag 3316 including strobes and VASI. The markings on the runway and taxiways were in accordance with Stanag 3158 AML. All required maneuvers could be trained successfully with the existing prototype CGIVS.

2. En route flight included terrain following and navigational up-dates using head-up display. The average height above ground for terrain following missions for the TORNADO aircraft was 200 feet. For flights in accordance to visual flight rules (VFR) the selected altitude was somewhat higher and depended on the weather. The navigations system of the TORNADO required intensive training in the following procedures:

a. Fix-up dating of the navigation system.

b. Input of offset fixes and other non-preprogrammed navigational fix-points.

c. Cooperation between pilot and observer during different phases of fix-up-

dating.

d. Terrain following transition from automatic to manual mode.

The data base for en route flying covered an area of 52 x 160 km (Altmuehl Valley). Up to an altitude of 1000 feet above ground, the highest level of detail was selected for the presentation by the CGIVS.

The results of the evaluation showed that the CGIVS prototype could not provide adequate training for these tasks. The resolution of the system (4 minutes of arc) was not good enough for event and object recognition, including navigational fixes. The real-time data base capacity of 10,000 edges was too small to allow allocation of enough three dimensional objects over the whole area of the data base in order to provide the simulator pilot with sufficient visual cues necessary to judge velocity, height and distance. Moving objects could not be presented in this data base due to the limitation of the capacity of the real-time data base.

3. Ground and sea attack - the effectiveness of the CGIVS in this area was evaluated using the presentation of tanks. The attack of tanks using the Bolkow dispenser is one of the major roles of the TORNADO aircraft and should, therefore, be trained with the simulator. The moving objects were integrated with data bases showing terrain.

The evaluation showed that the resolution of the CGIVS was not good enough for target recognition. The number of potentially visible edges to be displayed in one scene (2,000 edges) did not allow for presentation of targets with sufficient realism. An increase in the field of view (106^o horizontal, 26^o vertical) was desired.

4. Final phase of air-to-air combat - was dynamic with a high rate of change in perspective angle of view and a short time available for the required procedures.

It would have been desirable to train the following offensive maneuvers: high-speed yo-yo, low-speed yo - yo, barrel roll attack.

A Fishbed J was integrated in a data base showing terrain. The Fishbed J was modelled in the highest level of detail, but still was not detailed enough to provide the types of aircraft at greater distances when a larger area of terrain had to be shown by the CGIVS.

A higher level of detail could not be present due to the limitation of 2000 displayable edges in one scene. Also the resolution of the CGIVS was not good enough to provide event and object recognition in longer distances. Many of the above mentioned offensive maneuvers could not be trained with the CGIVS due to the limited field of view.

5. Inflight refueling and formation flying. A KC135 was modelled showing the boom of the tanker aircraft. The aircraft and the boom showed all necessary lights and markings generated by the CGIVS. The Fishbed J was used for training of formation flying. Both inflight refueling and formation flying could be trained successfully with the prototype CGIVS.

6. Standard air-to-ground range - bombing runs. The following attack procedures on a standard air-to-ground range were evaluated using the CGIVS: Strafing, rocketry, low-level bombing, low-level slide bombing, dive bombing, visual low-angle drogue deliver (VLADD), backup bombing, and lay down backup bombing. Standard air-to-ground range- Siegenburg Range was modeled for the presentation on the CGIVS.

All performance data of the CGIVS were sufficient for effective training with the digital visual system. Only a larger field of view seemed desirable.

7. Tactical air-to-ground range - Same procedures as 6. above using a tactical target such as SAM 3.

In summary, the prototype CGIVS for the TORNADO training simulator showed deficiencies in the following areas: Scene content was inadequate for the training of en route flying, ground attack and final phase of air-to-air combat due to the limited number of edges per scene.

Resolution was inadequate for the training of en route flying, ground attack and final phase of air-to-air combat. The field of view was inadequate for the training of the final phase of air-to-air combat and ground attack due to the number of channels.

The visual system lacked realism because the CGIVS had no texturing and curved shading capability. All faces were presented in uniform colors.

As a result of the evaluation performed, the general characteristics of the CGIVS for the TORNADO training simulator were modified as follows:

1. Number of channels increased to three and expandable to five in order to increase field of view.

2. Real-time scene capacity increased to 8000 edges and 4000 point lights.

3. An unlimited on-line data base was provided by dynamic reloading.

4. View plane elements were increased to 875 lines with 1000 elements per line resolution.

5. Texturing and curved shading was added.

An important aspect of the entire program was the successful cooperation and working relationship established between industry, the German Air Force and the Navy.

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APPLICATION OF THE CILOP PRINCIPLE TO SIMULATORS

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The acronym CILOP was coined by the Department of Defense just a few years ago. It stands for "Conversion in Lieu of Procurement" and was an attempt to decrease the cost of new programs. Although the acronym has almost faded into oblivion, the concept remains both valid and active.

The basic principle behind CILOP is to decrease the cost of programs by modifying existing systems rather than starting from scratch. This principle moves along two separate and distinct tracks, both starting from a common point but traveling in different directions.

The first track is a method of procurement with the objective of reducing costs associated with new contracts and the competitive process. Under this procedure, new requirements which become evident while a contractor is working an active program are added to his existing contract as an engineering change proposal (ECP). This eliminates lost time and the expense of contractor and proposal evaluation. The required paperwork for initiation of a completely new program is also eliminated. The principle has worked well for minor requirement changes, but its application for major changes has not been successful over the long term for either contractors or for the Department of Defense.

The second principle in the "Conversion in Lieu of Procurement" concept is what I like to refer to as the "building block" concept. Under this principle, a new product is procured only if an existing product cannot be modified to provide the required capabilities.

This concept embraces the basic principle of modifying present equipment to accomplish the same task as new equipment.

This aspect of the CILOP principle, very much in use, is also known as simple modification. It is used on prime systems as well as simulators and training devices, and is not confined to military sales but crosses the full spectrum of government and commercial markets.

Modification of prime systems has been occurring at an increasing rate over the past several years and promises to be just as active in the future. The nature of confrontation between two adversaries in a modern, technologically active environment is continual change by one side followed by change on the other side. The electronic warfare field is a perfect example of the ever changing environment. Technology has reached and surpassed the point of hardware only systems. The advent of software programmable signal processors and microprocessing techniques gives the user a capability to rapidly change his capability in response to new intelligence.

The expanded capability has led not to a decrease in new systems being purchased, but to an increase in the number and speed of modifications on older systems. The same principle is applied to our everyday commercial systems also. Each of us, except for our oil rich neighbors, will modify or repair our older vehicle before we scrap it for a new automobile. The same principle has been used in aircraft procurement for years. When the threat changes, we modify the aircraft subsystems to accommodate the new protection requirements. The aircraft is scrapped only when the modification would seriously degrade the flight envelope, or the airframe itself would no longer accommodate the necessary change.

The F-4 is an excellent example of an airframe which has been

continually modified with electronic countermeasures equipment to keep current with the changing threat environment. As a result, the F-4 has been a front-line aircraft for well over ten years and is only now being replaced by a new aircraft.

This same CILOP principle also applies to simulators which brings us to our primary topic. In the simulator procurement and modification market, the first CILOP principle, sole-source contracts, has actually had more application than the second principle. Perhaps this is due to the small costs of simulator modifications compared to the cost of prime systems changes. In either case, there is good reason for following both principles.

When a modification is made in a prime weapons system, the change must follow in the simulator. The changes in the simulator should emulate as closely as possible the modifications in the weapons system and should be made in as timely a manner as is possible. The amount of time available from definition of the prime system change and incorporation in the platform is not always sufficient to allow for a competitive procurement procedure. The simulator must keep pace with the weapons system or negative training will result. Therefore, although simulator contracts have not been open-ended with ECP action, a common route to modification, sole-source procurement has ocurred to a great extent. This has saved the Department of Defense money in most instances and resulted in good products that respond effectively to prime system changes.

The second principle, modify rather than buy anew, has been used successfully in the Electronic Warfare (ECM) Trainer field. Since ECM is the fastest changing medium today for the DOD, the B-52 ECM suite appears to be the best example to use to explain the pros and cons of this principle in simulator applications.

As an introduction to this simulator, I should mention that the present B-52 ECM suite utilizes a conglomeration of receivers and jammers that cover the full spectrum of the enemy radar environment and utilize technologies covering the time period of 1960 through 1978. This collection of systems are loosely tied together in an integrated system with the Electronic Warfare officer as the central manager. Due to this loose association of equipment, an individual system can be easily modified to accommodate the changing threats with no effect on other systems.

The cost effectiveness of modification or replacement of individual equipments on the B-52 becomes strictly a question of capability desired. The simulator is a completely different problem.

The B-52 EW simulator is the AN/ALQ T4. As originally designed, the T-4 was an analog system utilizing technology that was current in the early 1960's. When the first modifications in the aircraft's ECM suite were initiated in about 1965, it was decided to upgrade the T-4 rather than to procure a new simulator. Similar decisions have been made with each aircraft change to date.

In the process of modifying the T-4 to simulate new aircraft equipment, the analog equipment has been upgraded to a digitized system. This conversion effort was in part necessary to accommodate the new demands placed on the equipment and partially due to a natural evolution in technology. The new technology was automatically incorporated with each modification as a life-cycle cost savings procedure, as a result of adding state-of-the-art techniques to each modification effort. The finished product is inherently more capable of performing the required tasks, is more flexible in accommodating new requirements, and has resulted in keeping the training concurrent with operational equipment.

Virtually all systems are controlled and monitored by a central computer. Modifications within a system can easily and quickly be accomplished in the simulator by a software formulation change. The addition of a new system aboard the B-52 can be accommodated in the simulator by changing the software and adding hardware. The less costly route has always been a simulator modification, rather than an altogether new simulator. This route has proven successful for the addition of the ALQ-117, ALQ-122, and the ALR-46 equipment, as well as the conversion of the older ALT-13 transmitters to ALT-28s and finally, to an ALQ-155 Power Management System. This "Conversion in Lieu of Procurement" practice has worked well for the T-4 simulator and, although it has predominantly been a sole-source procurement program, key modifications have been open to competitive bid.

By looking closely at the advantages and disadvantages of buying new instead of modifying, we can build a strong case for the CILOP principle. Seven points appear relevant:

1) Percentage of change

2) Schedule

3) Operational training loss

4) Risk

5) Maintenance training/support equipment

6) Investment

7) Costs

These seven points should be evaluated in detail for each new simulator requirement when an existing simulator is already operational.

The first point, percentage of change, should be measured twice. If the simulator change is minor, should not the present equipment be modified rather than rebuilding the device from scratch? The basic system hardware is there and the technology will not change. Why re-invent the wheel? On the other hand, if the changes are in fact major, and the entire student booth/instructor station/and integrating circuits need changing, perhaps starting over is a proper and cost-effective approach. The second measurement is made after production of the new prime weapons system is complete. Are further modifications likely to occur which will require simulator modifications? Will these modifications have dire effects on the simulator, or can they be incorporated easily? In the EW trainer, the answer differs for the two measures. No, the requirements for change are not so radical to cause a complete change in the current simulator. The T-4 can be updated without excessive cost by adding software and hardware changes to incorporate all the new training requirements. The second answer is "yes", modifications are envisioned far into the future. Any new trainer must remain easily modified to adhere to modification time and cost constraints.

The second and third points to consider are schedule and training loss. Anytime a new simulator is procured, there is a time lag from when the simulator is ordered, initiation of the prime system modification, to the delivery of a fully operational trainer. This time lag results in a definite loss of training, which can be catastrophic during tense world situations. The finished simulator product must accurately reflect the actual aircraft operation. In the case of ECM systems, the full integrating effects of new equipment has never been accurately definitized before the prime system has become operational. Can a new simulator afford to wait until the prime system is flying and then start development? Does the new simulator go into production and then retrofit after the prime system is operational? Either way, training time is lost. In

the conversion concept, training continues and, since the modification may be only minor hardware change, the simulator can be updated very quickly after the prime system is finalized.

Risk is the fourth point and is very subjective. Assuming a new simulator procurement is not a redevelopment of the wheel, how much risk is involved in the development process? If training is relying on the new simulator within a key specified time period, what confidence factor will be applied to the new approach as to meeting the time schedule with the required operational capability? The risk is high with any new system and will increase dramatically with the amount of sophistication required. Modification of an existing simulator does not entail the same risk even though the final product will be the same. The existing simulator is proven. Only new portions of the hardware or software would have any attendant risk factors.

The fifth point is related more to overall program cost and personnel utilization than directly to the contractor charges. Procuring a new system usually requires new or different accompanying maintenance equipment. In addition, the maintenance personnel will require retraining in the total system and will still be relatively inefficient for a period of time while their experience level builds. A critical point is whether sufficient personnel resources are available to support a large program or will contractor support at additional cost be necessary.

Investment is the sixth point and requires extreme scrutiny. With tight budget dollars, scrapping or discontinuing the use of a good working system must be thoroughly justified to prevent serious loss of confidence by the public and, thereby, an ultimate loss in new year funding. The question of when an older system is no longer usable is totally dependent on mission and maintainability costs. If the mission has not changed and the maintainability costs have not risen sharply on an operational simulator, why risk an untried new device?

The last point and the one which will normally receive the largest percentage of attention in simulator procurement is cost. How much is the new system and what is the difference in cost between a new system and the modified existing simulator? The importance of cost and the relative evaluation points assigned to them is purely subjective.

At what point does the defense establishment opt for a new system rather than for conversion of an existing device? Where is the line drawn and how is that line justified? Is there a CILOP checklist which includes the seven points we discussed or may be respectfully submit these seven points as a starting point?

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RADAR WARNING TRAINING DEVICES

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ABSTRACT

The proliferation of sophisticated hostile radar-directed weapon systems, and the complexity of modern radar warning systems (RWS) dictates that our aircrews be thoroughly trained in the techniques of electronic warfare (EW). Mission success is directly dependent upon the aircrew's competence in interpreting the threat environment via the radar warning displays and their ability to react quickly and correctly to this threat situation. This competence and ability are achievable only with extensive, high-caliber training. To provide this training within today's time and economic constraints requires multiple training media, utilized to produce the most cost-effective combat ready results.

This paper suggests augmentation of existing academic and flight-simulator training with a hands-on interactive desk-top trainer for improved indoctrination and refresher training, as well as in-flight simulation to reinforce this training in a high-stress environment.

The paper describes a compact universal desk-top trainer which is software programmable to simulate the user's radar warning system. A method of entering and changing threat data and creating mission scenarios for the trainer, which requires no programming ability, is described. The paper also discusses in-flight simulators which provide simulated threat presentations on the actual radar warning equipment and display threat responses to flight and tactical maneuvers.

1.0 INTRODUCTION

Radar warning systems (RWS) on military aircraft provide visual and aural indications to alert the aircrew to the presence of potentially hostile radar-directed weapon systems.

Visual cueing of threat type, azimuth relative to aircraft heading, and lethality is displayed on a cathode-ray tube azimuth indicator. Aural cueing, by means of converting detected video pulse trains to audible signals and generating warning tones, is available through switch manipulation on a control panel. The cues provided by the RWS are a valuable asset to the aircrew, providing specific information on relative location and operating mode of hostile installations. Tactics to respond to hostile installation activities must be performed under the heavy task loading associated with battle-area penetration, weapon delivery and enemy engagement.

The ability to quickly recognize and react to multiple-threat warnings in a dense-threat environment is crucial to aircrew survival and mission success. The familiarity needed for RWS operation, threat recognition and counter tactics requires extensive training. Thus, there is an obvious need for cost-effective training devices tailored specifically to the overall training problem.

Basic indoctrination of service personnel to radar warning systems and hostile weapon systems, appears to be limited to classroom lecture-type training. This training appears self-limiting, in that the student's retention in a non-interactive situation is typically less than 25%. Additionally, varying student and instructor capabilities directly affect the quality of training.

Tactics against threat situations represented by the RWS displays are introduced in the flight simulator. Heavy task loading and limited availability can sometimes prevent thorough indoctrination in this phase of training.

Reinforcement and refinement of EW training received in the classroom and simulator is provided by some of the services in an in-flight environment. Here, the aircrew responds to ground-based "live" emitters, simulating hostile weapon system radars. If the lessons learned in the classroom and simulator do not produce almost instinctive responses, valuable flight time is lost.

A desk-top trainer can provide an extra dimension of learning in the classroom which can enhance the effectiveness of not only classroom, but simulator and in-flight training also. A portable, microcomputer-controlled trainer providing visual and aural threat presentations on actual cockpit RWS hardware enables an added degree of realism and flexibility. With such a trainer, the one-way classroom indoctrination training of RWS and weapon systems is converted to a hands-on, interactive learning situation with the probable results of better retention and increased learning motivation. Using this trainer in the calmer classroom atmosphere to repetitively demonstrate the dense RWS threat displays and their motion which occurs in response to basic flight maneuvers, can provide

the initial EW competence needed to fully utilize the task-loaded simulator for effective tactical maneuver training. In addition to providing thorough indoctrination training in RWS operation, weapon systems and RWS display response to tactics, the trainer can be effectively used in self-pacing refresher training. With a thorough grasp of the RWS operation, weapon systems and RWS tactical responses, the aircrew can now be ready to exploit the more realistic but more costly high-stress in-flight training environment.

2.0 CLASSROOM TRAINER

2.1 Application

The desk-top RWS classroom trainer provides a ready means of indoctrinating students in radar warning system operation, hostile weapon systems recognition and resultant RWS threat displays, along with threat-display behavior in response to flight and attitude changes. Additionally,it serves as a refresher trainer to maintain proficiency in electronic warfare.

The electronic warfare instructor will find the desk-top RWS trainer a valuable aid in teaching RWS operation effectively through hands-on interactive training. The student receives instant feedback of his control/indicator initiated RWS mode activation and changes, and can be immediately corrected when he chooses wrong modes for given tactical situations (e.g., AAA defeat actuation when the posed tactical problem has him flying low altitude). The student can be effectively taught the Target Separate, Priority, System Test, Search, Handoff, Unknown, Missile Alert, Launch, AAA Defeat and Power functions (AN/ALR-46) with the resultant displays appearing immediately in response to his actuations. Some of the more confusing sequential mode selections (e.g.,AN/ALR-46A "Training" mode) quickly become rote with the tactile, visual and aural feedback resulting from his selections. The instructor has immediate feedback as to the student's ability and knowledge, allowing instant correction. Consequently, the student is made proficient in minimum time.

During indoctrination training on hostile weapon systems, threats take on added meaning when the displays on the RWS are used. The prf of the radar can be heard, the symbol identifying the threat can be seen,and the lamp, auditory and symbol warning displays accompanying a launch make the threats more real to the student. Threat behavior such as the classical low-prf, high-prf, activity, launch sequence of certain radars, can be more effectively demonstrated with the visual and aural effects. The instructor has complete control of the training situation by means of the keyboard. He can initiate the desired training situation, repeat the problem, or change the situation as the student's progress warrants.

The instructor can also demonstrate threat-display behavior in response to dead-ahead flight, level turns or attitude changes. This allows him to introduce the confusion in the display resulting from maneuvers, without the distraction of flying a simulator or aircraft. Proficiency in interpreting the RWS displays allows him to more effectively use the simulator or in-flight situation to hone his tactics.

The trainer with its automated scoring option is also ideally suited for refresher training. This can be accomplished by the student calling up threats using the keyboard or by programmed tapes that guide the student from basic single threat recognition to identifying threats in a multi-threat environment. The tapes can be annotated with voice to provide threat identification and to guide the student through the learning situation.

2.2 Description

Radar warning system trainers have been supplied to various users. One of these, a minicomputer-controlled unit (Figure 2-1), was the precursor to the microprocessor-controlled trainer described in this paper. Shown in Figure 2-2 is the production configuration of the compact desk-top trainer.

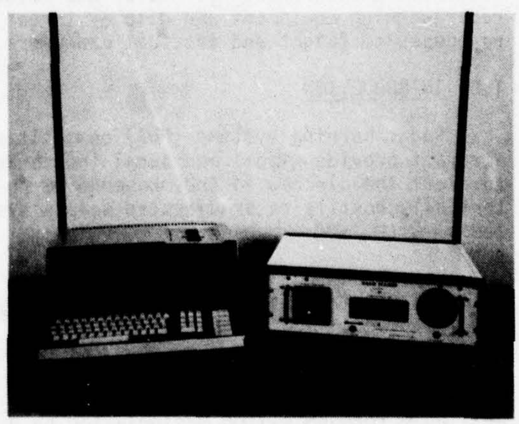

Figure 2-1. Minicomputer-Controlled Radar Warning Trainer

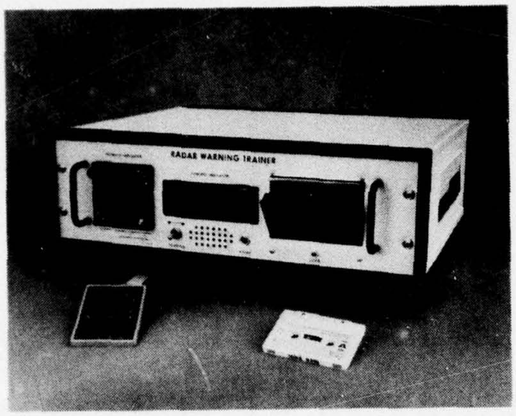

Figure 2-2. Microcomputer-Controlled Radar Warning Trainer

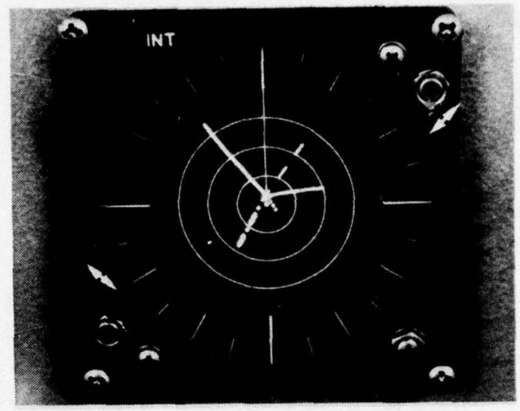

Figure 2-3. Radar Warning Trainer Strobe Display

The trainer is approximately 6 inches high, 19 inches wide and 21 inches deep, weighing about 40 pounds. The front panel contains the actual azimuth indicator and control indicator as used in the specific radar warning system (RWS). A self-contained tape deck provides for loading of the specific RWS program and the user-generated mission scenario. A handheld keyboard allows control of the mission scenario and retracts for storage in the rear of the unit. A heading control switch allows student-initiated heading changes. Threat audio is reproduced by the front panel speaker or by headphones connected to a front panel jack.

Classified threat simulation, specific RWS simulation and scenario simulation programs are stored on magnetic-tape cassettes for loading in the microcomputer's volatile memory. The unclassified trainer hardware is configured to produce authentic threat audio for 16 simultaneous emitters and to generate 16 accompanying strobes or alphanumerics on the azimuth indicator. Actual flight hardware is used for the azimuth indicator and control/indicator units. Many of the radar warning systems use basically the same displays and indicators; the trainer hardware accepts these without modification. The software program is configured to simulate the user's specific RWS logic, so that by simply loading the desired RWS software cassette, the trainer can be configured to simulate any of the above systems.

This universality should make the trainer particularly attractive to users who have fielded several different radar warning systems, such as the Navy with the strobe ALR-45 and the planned alphanumeric ALR-45F and ALR-67; and some Air Force units deploying ALR-46 and changing to ALR-46A or ALR-69 systems.

Figure 2-3 illustrates strobe threat displays on the trainer.

A functional block diagram of the basic trainer is shown in Figure 2-4. The audio and display generation is under control of a microprocessor with 16K bytes of volatile (RAM) memory and 4K bytes of firmware (PROM) memory. The RWS simulation software and user-generated mission scenario data are loaded into the volatile RAM memory from the magnetic tape cassette at power-up. Utility programs and math routines are stored in the firmware. Audio is produced under program control by a programmable pulse generator. Data defining pulse repetition frequency (PRF), scan frequency and search frequency are loaded into the hardware, which operates on this data to produce up to sixteen simultaneous authentic threat audios. A programmable display generator provides for strobe or alphanumerics generation under software control. This versatile circuitry produces either coded strobes or threat-identifying alphanumerics when the appropriate simulation software is loaded. The microprocessor communicates with the tape deck for program load and with the keyboard for mode selection and manual threat entries. Also, communication with the control indicator is established via command and lamp interfaces. Figure 2-5 illustrates an alphanumeric display.

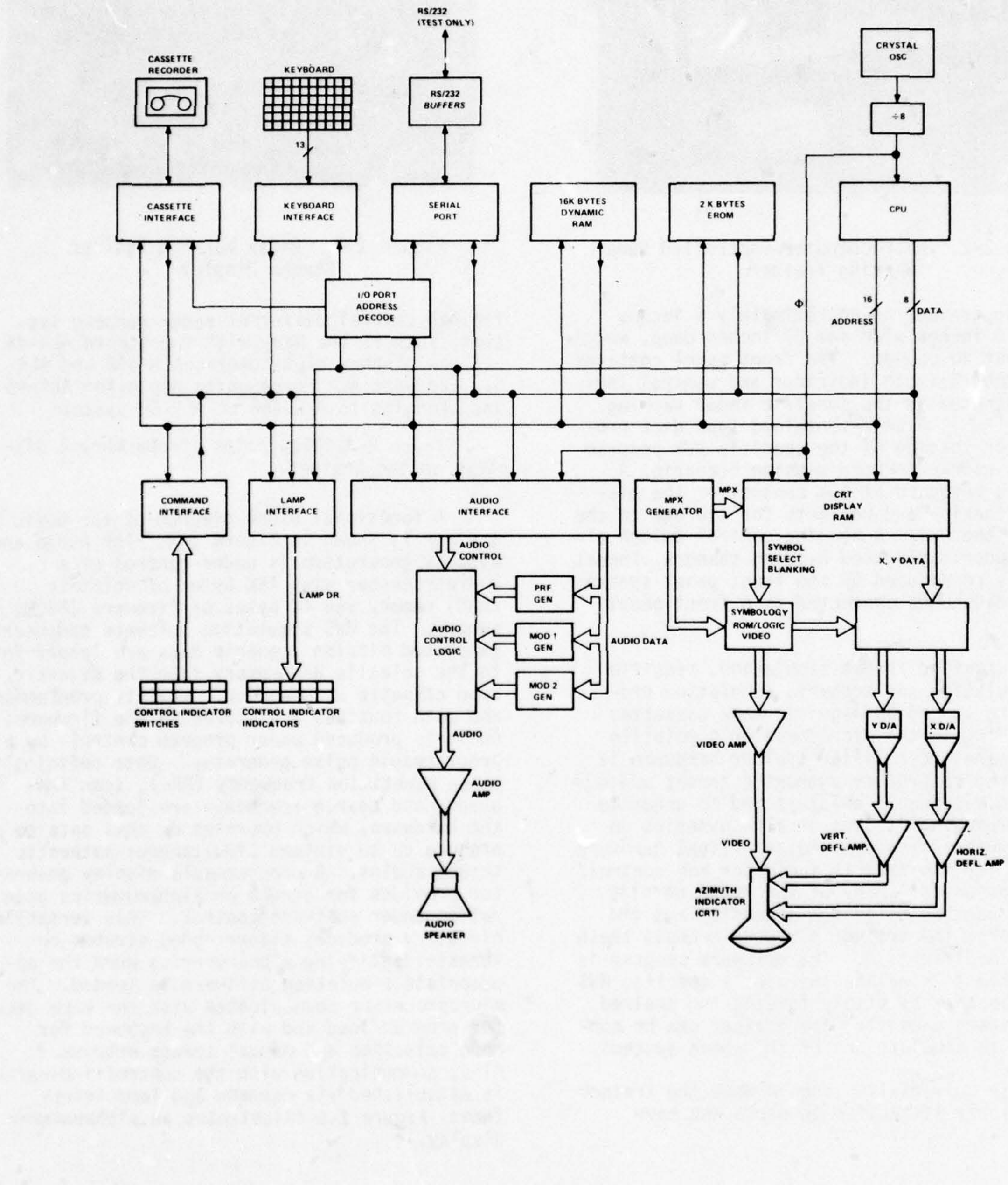

Figure 2-4. Desk-Top Trainer, Functional Block Diagram

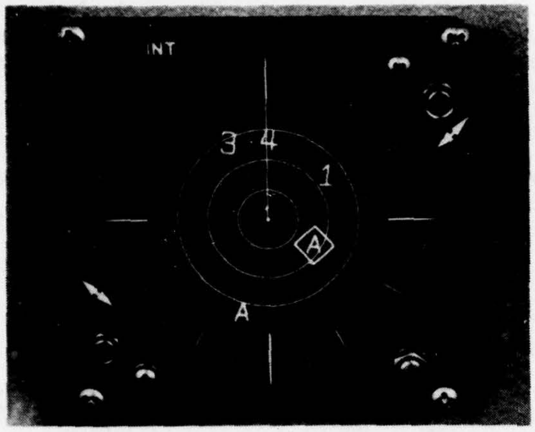

Figure 2-5. Radar Warning Trainer Alphanumeric Display

A number of options to the basic trainer have been developed or planned which further enhance its usefulness: Pitch/Roll simulation, Voice Annotation/Self-Teaching, and Tactical Situation Display. These are described in later sections.

2.3 Capabilities

The desk-top RWS trainer features the following capabilities:

- Easily portable for classroom use.
- Unclassified hardware - classified software on easily stored tape cassettes.
- Software programmable to simulate a wide variety of Radar Warning Systems: AN/APR-25, -26; AN/APR-36, -37; AN/APR-39(V)2; AN/ALR-45, -50; AN/ALR-45F; AN/ALR-46; AN/ALR-46A; AN/ALR-67; and AN/ALR-69.
- Dynamic threat simulation - threat strobes or alphanumerics realistically respond to aircraft flight and heading changes.
- Authentic threat audio - programmable pulse generator produces Search, Track While Scan, Conical Scan, Raster Scan, etc.
- Automatic, "canned," scenario presentation or instructor controlled scenario from keyboard or a combination of both.
- User easily generates his own library and scenario/mission data using non-programmer personnel.
- Pitch and Roll simulation option (requires added control).
- Situation display option to demonstrate the geographic threat situation corresponding to the lethality/azimuth threat display.
- Voice annotation/self-teaching mode option for student paced learning.

2.4 Operation

2.4.1 Basic Trainer - The trainer is ready for operation upon application of power and loading of the program and scenario/library tapes. With the keyboard, the instructor may enter threats at the desired range and bearing for each; he may change the mode or status of any threat, or he may initiate the programmed scenario. While the scenario is operating,he may overide the action of any threat or add new threats. During a programmed scenario, simulated threats occur at the time into mission and at the relative azimuth and lethality signal strength programmed for each. The programmed scenario consists of a maximum of 200 events. An event can be the insertion of a new threat or changing a previous threat's mode, missile status or position.

At any time the student may operate the RWS controls as in normal operation; i.e., termining priority of the displayed threats, defeating AAA, permitting unknown threats or search radars to be displayed, separating targets, and so forth. When he initiates aircraft heading changes by means of the front panel switch, the threats displayed will respond to these changes by moving to the approximate new relative bearing and range.

2.4.2 Library/Scenario Preparation - The characteristics of the 32 threat types have been separated from the main trainer program and grouped into an area called the threat library. This library contains the threat audio characteristics (pulse repetition frequency, scan rates, walk-through parameters and raster rates), symbol displayed, priority, lethality and other characteristics which determine how the threat is presented on the radar warning system. Thus the addition of new threat types or changes to existing threats requires only changes to the threat library. The scenario definition has also been arranged so that it can be changed easily without affecting the radar warning system simulation. Therefore,new scenarios can be generated to correspond to a new operational area or a new training plan. To prepare a library or scenario, the data is first tabulated in a form familiar to an instructor or pilot. The threat characteristics may be obtained from an updated Emitter Identification

List or from current intelligence data. Typical threat characteristics needed are threat type, audio prf, audio scan type and rate, priority, lethality, and symbol displayed.

To create a scenario, the events are listed in chronological order with an event being a threat change,or an aircraft heading, or speed change. The scenario could correspond to a training or operational area or it could be a simple scenario used for initial indoctrination. A typical scenario entry is as follows:

Time:	2 Minutes, 15 Seconds
Threat:	Gundish, Search Mode
Location:	5 Kilometers, 1:00 O'Clock

After tabulating the library or scenario, it is entered into the classroom trainer, using the instructor's keyboard, in response to cueing presented on the azimuth indicator. The data is then transferred to cassette tape ready for use in the trainer.

2.4.3 Trainer Situation Display Option - The RWS azimuth indicator displays threats within the range and capability of the radar warning system. Threats are identified by their radar signature and displayed relative to the ownship heading at a distance depending on lethality and signal strength. The radar warning system cannot identify or totally resolve some threats,and displays some as unknown or ambiguous threats. Also some AAA, unknown, and search radar displays are purposely disabled by the RWS operator to prevent a cluttered display. Therefore,the RWS azimuth indicator does not give a complete indication of the total-threat environment.

To train students in the interpretation of the RWS displays, some means are desired to relate the RWS displays to the geography of the ownship flight path. The situation display presents the threat geographical situation on a standard TV monitor. The location of each threat site and the identifying parameters for the threat are shown on the situation display. The ownship location and track are also shown with the ownship track remaining throughout the mission.

The use of the situation display aids in critiqueing the mission profile and simplifies simulated mission debriefing. Malfunctions and inadequacies of the radar warning equipment can be demonstrated using the situation display and the proper simulated in-flight corrective actions by the aircrew can be observed and taught. Since an entire gaming area is shown on the situation display, enemy radar deployment can be illustrated and the proper tactics to use against the simulated hostile radar environment can be illustrated.

The situation display feature is implemented on the desk-top trainer by the addition of a circuit card and a video connector located in the rear of the trainer. The trainer then connects to any standard black and white TV monitor. A 19-inch or larger monitor is recommended for classroom use. The software for generating the display is contained in the trainer operating program and is loaded from the cassette containing the main trainer program. The situation display illustrates both threats entered manually from the keyboard and automatically from a preprogrammed scenario. The flight of the ownship aircraft is also shown in the automatic and manual modes.

2.4.4 Automated Training and Scoring Option - In order to provide instructor-independent RWS training, a means of automated classroom training and scoring is desired. Training and scoring should be provided in the following areas:

AREA	SKILL REQUIRED
Threat Recognition	Correctly determine threat parameters (type, lethal range, operating mode) and assess threat potential.
RWS Operation	Correctly set up RWS controls to provide and limit visual and/or aural cues as appropriate (AAA defeat, Unknown defeat, Mode select and display controls).
Electronic Countermeasures	Determine the optimum counter to the threat (chaff/flares/jammers).
Maneuvers	Employ defensive tactics in a timely, effective manner.

Automated training and scoring on the RWS desk-top trainer is planned with the basic trainer configuration using the cassette unit, keyboard and RWS controls as training aids. Training and testing exercises are recorded on cassette tape. This includes voice annotation and digital data. The voice annotation can either describe a particular threat or group of threats for an instructional exercise, or present a question as a testing exercise. The digital data initializes the trainer for the desired operating mode and threat display. The keyboard and RWS controls are used to capture the student's response.

For an automated training exercise, the student or instructor would select the appropriate cassette consistent with the training level desired and insert it into the trainer cassette unit. The trainer is now ready to present the training exercise at a pace selected by the student or instructor. Single or multiple threats are enabled with the

appropriate RWS visual and aural cues. Each training situation may be voice annotated as to type, lethality and operating mode of the displayed threats.

For an automated testing exercise, a test tape of the desired proficiency level is loaded. Testing is automatic at a pace determined by the level of test exercise. Threats are presented on the RWS displays with the appropriate warning tones and lights. Voice annotation is used to ask the student questions concerning type and mode of the threat or optimum counter to use against threat. The student responds using the handheld keyboard and receives feedback as to the correct answer on the keyboard. A cumulative score is calculated by the trainer and presented to the student and/or instructor at the end of the training exercise.

3.0 IN-FLIGHT TRAINERS

A natural extension of desk-top trainer and full mission simulator development is the development and application of electronic warfare in-flight training techniques.

In-flight electronic warfare training provides the high-stress, task-loaded environment which our aircrews will encounter under actual combat conditions. This "white-knuckle" environment provides a dimension of training reinforcement not possible with any other training media.

Present methods of providing this training environment consist mostly of constructing specific ranges containing live emitters which simulate enemy radars. Even with these ranges, however, it is difficult to provide the threat density and threat placement necessary to accurately simulate the battlefield environment. Acquisition, operation and maintenance costs for these ranges are often high. Present availability of ranges is limited because of the large number of aircrews requiring training. This necessarily limits the amount of time each crew can spend on the range each year.

An onboard in-flight trainer can augment or supplant range installations, providing for effective in-flight training in electronic warfare under high task-loading and realistic stress conditions. We have studied several approaches to in-flight EW training. Some of these have been in-house funded, and others have been under contract to the U.S. Army.

There are several constraints which complicate the task of developing acceptable in-flight training devices. Among these are the requirements for little or no modification of the aircraft and for adding no extra weight. Additional requirements are the need to detect aircraft attitude and position to provide information to the in-flight trainer for proper positioning of the simulated threats. A means must also be provided for controlling the threat presentations so they are coordinated with those of accompanying aircraft.

Investigations into these training concepts have thus far led to the conclusion that there is no one system which can effectively satisfy all requirements of all potential users of such a system. There do appear to be several approaches or combinations which offer compromise solutions and still can provide effective, economical in-flight electronic warfare training. Further study and development are continuing to optimize these concepts to provide a viable in-flight electronic warfare training device.

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A NEW CONCEPT FOR APPLICATION OF MICROCOMPUTER TECHNOLOGY TO REAL-TIME TRAINERS

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ABSTRACT

This paper presents a summary of an analysis of a new and unique concept of microcomputer technology application to real-time trainers that has been developed by NAVTRAEQUIPCEN. It summarizes the technical objectives, the conceptual analysis, technical feasibility, and life-cycle cost trade-offs. The required technologies for system implementation are identified and a status of the exploratory development to achieve the required technologies and demonstrate concept feasibility is provided.

INTRODUCTION

Over the past decade, the proliferation of digital computers embedded in trainer systems with the attendant proliferation of assembly-level languages has resulted in increased life-cycle costs of all types of real-time trainers. Large scale integration (LSI) and very large scale integration (VLSI) technology now available and embodied in state-of-the-art microprocessors and microcomputers suggests computer system architectural concepts that potentially can reverse this proliferation. Further, these concepts offer the possibility for extensive hardware - software modularity, hardware - software standardization and overall performance improvements with significant reduction in life-cycle costs of all types of real-time trainer systems.

Various concepts of microcomputer system architectures with applications for trainers have been under investigation at NAVTRAEQUIPCEN for over two years. A unique concept has evolved from this investigation. This concept will implement computer system requirements for trainers with a series of microcomputers organized in a multiple configuration. The system will control and provide the required computation for the total trainer with a stored program that has been functionally partitioned. The partitioned functions are dedicated to individual microcomputers.

This paper presents a summary of the conceptual analysis, the technical objectives, the feasibility and cost trade-offs. The required technologies for implementation are identified.

Finally, a status of the exploratory development to provide the critical technology and demonstrate concept feasibility is discussed briefly.

PROJECT OBJECTIVES

There were four primary objectives of this research project as follows:

a. To lower life-cycle costs of trainer computer systems and reduce proliferation of different computer types.

b. To improve computer systems processing performance without increasing costs or hardware complexity.

c. To achieve the ability to optimally tailor the computer system capability to the requirements of a specific trainer.

d. To preclude early equipment obsolescence as the commercial computer technology advances.

Conceptually, each of the above objectives will be achieved in the system architecture and application of microcomputers introduced and described in this paper. Ultimately, life-cycle costs of trainer software can be significantly reduced via modular standardization of generic (common) functions that will be programmed in the new DoD standard HOL, ADA.

TYPICAL TRAINING SIMULATOR

In order to place this microcomputer approach in the proper perspective, a typical training simulator will be discussed briefly. Figure 1 provides the generic or stereotyped system configuration of practically all modern real-time trainers. In such trainers a general purpose (GP) digital computer and stored program are the key elements. The instructor's station provides the instructor with the capability to interactively control, manage, and monitor the training task, training scenario and the performance of the trainee through the medium of the GP computer system. The GP computer system interfaces with the external trainer equipment via linkage equipment that provides signal conversion, translation, input-output, etc., in conjunction with the trainee

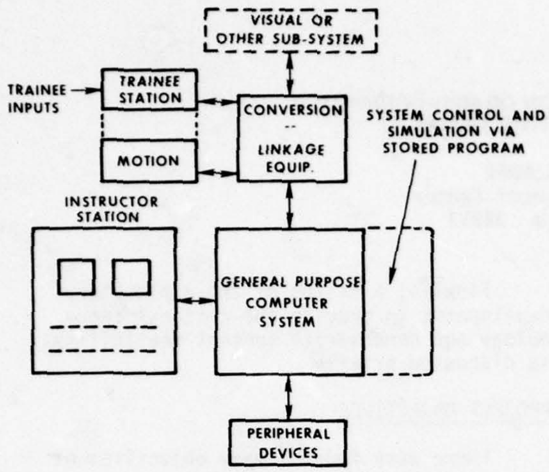

Figure 1. Typical Trainer System Concept

station and other subsystems. For a given trainer, there may be a motion system to provide the physical motion environment of the simulated weapon platform (e.g., an aircraft cockpit). The linkage and conversion subsystem also interfaces with any visual or other subsystem required for a particular trainer.

Computer peripheral devices such as CRT control terminals, magnetic tape devices, disc units, printers and the like, provide the capability to input the simulation programs, to input initialization data, and data bases, to print-out performance parameters, and to log specific trainer events. The disc units provide mass storage for all types of programs as well as storage of real-time data and parameters for playback to the system.

The program stored in the GP computer provides the system capability to process and compute the math model that represents the vehicle or system being simulated for training and to control the total training exercise in real-time.

It is appropriate to comment on some of the characteristics and deficiencies of the generic trainer computer system. The complete real-time program is usually stored in contiguous memory space of the GP computer. For trainer systems requiring more than one computer, the program is divided according to the operations and functions assigned to the several computers. In this type of configuration, one computer is designated as the master computer and the other computers are designated as slave computers. They normally communicate or pass parameters via a common memory. In all cases, the program is executed sequentially and concurrently and thus usually requires very high speed GP computers.

The computer hardware for trainer systems is selected by the trainer system contractors based on NAVTRAEQUIPCEN procurement policies and the technical requirements of the NAVTRAEQUIPCEN specifications. Cost-effective and performance considerations for selection restrict the computer equipment to a very limited number of computer manufacturers. Current state-of-the-art in computer main-frame hardware designs are not sufficiently modular for flexible low-cost system synthesis and/or low-cost system expansion for a wide spectrum of trainer classes.

There is no standard assembly-level language among computer manufacturers. Even the available high order language (HOL) FORTRAN is not optimum for programming high fidelity real-time trainers. There are no standard software modules regardless of mathematical or other model similarities among trainer classes. Thus the NAVTRAEQUIPCEN must pay for "re-inventing the software wheel" with each new procurement.

Limitations on processing performance of available computer hardware that is cost effective for trainers, and significant acquisition and life-cycle support costs of software, were driving functions in a search for concepts to apply microcomputer technology to trainers. The concept as developed is primarily applicable to replacing the GP computer function as described above and as depicted in Figure 1.

The initial part of the analysis was directed toward deriving GP computer performance requirements for a modern aircraft operational flight trainer as an example. Average performance figures are shown in Table 1.

The GP computer processing requirements as indicated cannot be accommodated by a single cost effective computer. The computer system was organized in a master-slave configuration, requiring a minimum of three GP computers.

PROGRAMMING AND EXECUTION REQUIREMENTS - TYPICAL OFT

Because of the sampled data and discrete nature of the variables as processed by the GP computers in a modern trainer, the solution of the vehicle simulation equations of the typical OFT is iterative. Of significant importance in determining the rate at which the variables must be sampled and processed is the highest natural frequency of the system or vehicle being simulated. Studies have determined that adequate simulation fidelity requires the solution rate must be at least 20 times the highest natural frequency. For modern high

TABLE 1. TYPICAL MODERN OFT PROGRAM PROCESSING REQUIREMENTS

SIMULATION FUNCTION	SIMULATION PROGRAM REQUIREMENTS* (INSTRUCTIONS PER SECOND)
Flight Control, Equations of Motion, Aero, Cockpit Inst.	917,063
Navigation/Communication	70,623
Accessories	12,066
Instructor's Station and Displays	42,188
Executive	111,375
Real-Time Operating System	27,338
Total for Typical Modern OFT	1,180,653 IPS
Average Instruction Execution Time Required by a Computer System	0.847 μsec/inst

* Includes 15 percent for FORTRAN inefficiency, 25 percent spare and 10 percent estimating contingency.

performance aircraft the highest natural frequency can be of the order of 1.0 to 1.5 HZ or even greater. Therefore the solution rate (iteration rate) of the simulation equations representing such a system must be executed at a rate of 20 to 30 HZ. If a visual subsystem employing displays with the standard TV raster frame rate is a part of the trainer, then the solution rate should be at least 30 HZ or an integer multiple of 30 so as to reduce system time lags and frame synchronization problems.

The high solution rates of real-time trainers impose stringent requirements on the capabilities of the computer hardware. The average processing requirements in instructions per second (IPS) for the various software groups of a typical modern OFT are shown in Table 1.

A standard set of generic computer instructions with percent usage (Table 2) was selected and families of microcomputer components were analyzed for equivalent performance in executing the selected set. The results of that analysis are tabulated in Table 3. As will be noted, the processing performance capabilities of the selected modular families show a wide range of average instruction execution times (AIET). Execution time capability was only one of the analysis criteria applied to modular families of microcomputers.

TABLE 2. SELECTED INSTRUCTION MIX (WITH PERCENT USAGE)

INSTRUCTION TYPE	PERCENT USAGE
Load	0.158
Store	0.128
Add/Subt	0.090
Multiply	0.047
Divide	0.008
Logical	0.076
Shift (5 places)	0.031
Compare	0.043
Branch	0.105
Index	0.003
Reg-to-Reg Opns	0.031
Miscellaneous (e.g., calls to O/S, etc.)	0.279
Input-Output	0.001
Total	1.000

TABLE 3. AVERAGE FIXED POINT INSTRUCTION EXECUTION TIMES (AIET)

MICROCOMPUTER FAMILY	AIET μSEC/INST
TI-SPP-9900	14.294
INTEL 3000 BIPOLAR SET	1.926
FAIRCHILD 9440	5.711
INTEL 8080A	52.782
INTEL 8085A-2	21.013
AM2900 FAMILY	1.401
MOTOROLA-MC-10800	1.209
TI-SN74S481, 482	1.531

MICROCOMPUTER SYSTEM ARCHITECTURAL CONCEPT

A new and unique multiple microcomputer system architectural concept for real-time trainers is graphically illustrated in Figure 2. The system concept consists of N microcomputers that are functionally dedicated to assigned portions of a total trainer program. They function as applications microcomputers. A control microcomputer exercises control over the complement of application and input-output microcomputers.

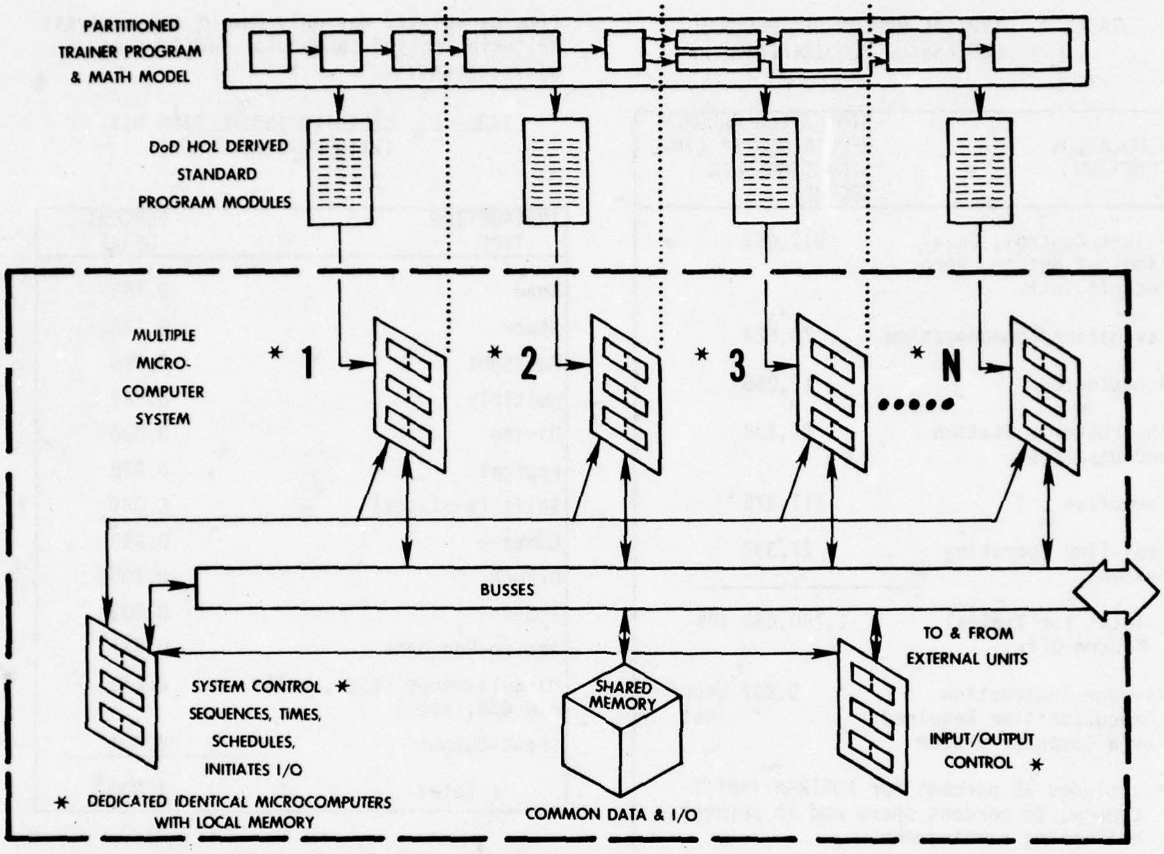

Figure 2. Functionally-Modular Multiple Microcomputer Concept For Trainer Systems

TABLE 4. TYPICAL OFT PROCESSING REQUIREMENTS PER APPLICATIONS MICROCOMPUTER

FUNCTION	INSTRUCTIONS PER SECOND	ASSIGNED MICRO-COMPUTER
Instructor Station, Misc.	169,000	1
Coefficients and Forces	308,000	2
Flight and Propulsion	265,000.	3
Axis Transformations and Integrations	181,000	4
Angular Position, Motion, TACAN	288,000	5
Instruments, Accessories, NAV/COMM	241,000	6
Total Applications IPS	1,452,000	

TABLE 5. SUMMARY - MEMORY AND AIET REQUIREMENTS

APPLICATION MICRO-COMPUTER	ESTIMATED PROGRAM SIZE (WORDS)	ESTIMATED TOTAL MEMORY (WORDS)	REQUIRED AIET (μSEC)
1	6784	7115	4.7358
2	4725	5325	2.5991
3	4556	5206	3.0157
4	2717	3129	4.4215
5	3459	3747	2.7821
6	7298	8423	3.2949
7	620*	1500	*
8	100*	750	*
9	100*	750	*
10	1000*	2000	*
COMMON MEMORY		16,000	

* Worst-case instruction execution should result in AIET's that are well within the actual AIET of the microcomputer technology analyzed.

The control microcomputer schedules and activates the application and I/O microcomputers that are to be active during each processing frame. This is illustrated in Table 6. The applications microcomputers that are active during each frame determine a system processing control state. Intermediate results, global variables, and other common data are exchanged between microcomputers via a common memory with a distributed cache address space. The distributed cache concept allows each microcomputer to write to all other microcomputers and to common memory,but each microcomputer can only read from the cache address space assigned to it. The control computer recognizes system interrupts that are generated by the elapsed time of a real-time clock or precision interval timer as determined by the highest solution rate (frame time). It also communicates with all applications and I/O microcomputers to initially load assigned program modules to each microcomputer. Ultimately, standardized functional code will be stored in a ROM in each microcomputer.

The typical OFT program mentioned previously was partitioned in a heuristic manner and assigned to individual applications microcomputers. As functionally partitioned, the simulation problem requires at least six applications microcomputers. The processing requirements (in IPS) of each functional group were analyzed and the results are tabulated in Table 4 with assignment to each microcomputer. Note that the total solution rate has been increased from 1,180,653 IPS (Table 1) to 1,452,000 (Table 4) for this specific example of microcomputer system implementation. This is the result of assigning all routines (of a functional group) dedicated to a specific microcomputer to be executed at the highest rate required within that functional group, rather than incorporating lower rates considered in the original problem analysis. This procedure requires a higher total computation rate but reduces the software (and ATM firmware) complexity and scheduling time overhead.

TABLE 6. MICROCOMPUTER SYSTEM FRAME/ CONTROL STATE SCHEDULING (EXAMPLE)

SYSTEM CONTROL STATE FRAME NO.	SCHEDULED MICROCOMPUTERS
1	1, 2, 3, 4, 5, 8, 9
2	2, 3, 4, 5, 6, 8, 9, 10
3	1, 2, 3, 4, 5, 8, 9
4	2, 3, 4, 5, 6, 8, 9, 10
5	1, 2, 3, 4, 5, 8, 9
6	2, 3, 4, 5, 6, 8, 9, 10
7	1, 2, 3, 4, 5, 8, 9
8	2, 3, 4, 5, 6, 8, 9, 10
.	.
ETC	ETC
.	.
60	2, 3, 4, 5, 6, 8, 9, 10

Table 5 is a summary of the estimated program size, total estimated memory requirements,and the AIET required by each microcomputer for the assigned functional groups of Figure 3. The microcomputers (#8, 9, 10) assigned the functions of input-output and instructor station control are shown along with estimated program sizes and total memory requirements. Specific AIET's were not derived,but by the nature of the assigned functions the AIET of 2.5991 μsec/instruction indicated for microcomputer #2 will be more than sufficient to handle the processing requirements of these functions.

The system control microcomputer (#7) was likewise not analyzed to the same degree of detail as the applications microcomputers. However, the system state control functions will not require a processing capability that should exceed that required by microcomputer #2 (the worst-case application AIET).

The total control of the system is implemented as a hardware-firmware-software algorithm. Within the context of this concept, algorithm is used to describe a set of hardware-firmware-software implemented procedures to obtain a given result. The criteria being used for the partitioning of the control algorithm into hardware, firmware, and software are processing performance, ease and economy of implementation and the ability to enforce necessary rules for concurrent programs. A general rule will be to implement the fixed portion of the system in hardware (microcomputer modular family) and to use software for the variable or application-dependent portions. Firmware will be used in place of hardware for those functions that will be common throughout the total system. Specifically, an applications task manager (ATM) concept has been developed and will be implemented in firmware as part of the total control algorithm for the ultimate system architecture.

All communications within the system (via a multiple bus structure) will be

MICROCOMPUTER NO.	SOLUTION RATE	ASSIGNED FUNCTIONS
1	30/sec	Instructor Station, DISPLAYS, Ground Reaction effects, taxiing
2	60/sec	Aero, Forces, Moments-Stab, Axis Comp. Atmosphere, Weight & Balance
3	60/sec	Flight Control, Propulsion system, Flight Control-CPU interface
4	60/sec	Stability Axis transformations, Earth-Axis acceleration Moments - Body Axis computation $\dot{P},\dot{Q},\dot{R}$ Integration, Air Data Comp.
5	60/sec	Angular Positions (Quaternions), G-seat/G-suit, TACAN Math Model
6	30/sec	Navigation, Radar Nav, Compass simulation
7	60/sec	System Control State
8	60/sec	Input-output - Cockpit
9	60/sec	Peripheral units control
10	30/sec	Instructor Station I/O and Controls

Figure 3. Microcomputer Designations (Example)

handled by a virtual machine implemented in the microcomputer firmware (ATM). The characteristics of the virtual machine concept will be independent of the hardware implementation. This will allow for substantial modifications or acceptance of new microcomputer technology without requiring changes in the fundamental control algorithm.

The ATM will function as a simple, highly efficient resource manager and real-time operating system for scheduling and controlling execution of the assigned tasks in each microcomputer. This also includes the control microcomputer whose assigned task is primarily that of master interrupt accounting and scheduling all other microcomputers for each frame or system control state (ref. Table 6). The firmware-implemented ATM is identical in each and all microcomputers.

MICROCOMPUTER MODULAR FAMILIES INVESTIGATED	ANALYSIS FINDINGS
INTEL 3000 BIPOLAR SERIES**	FAST, MICROPROGRAMMABLE, TOO INFLEXIBLE IN MICROCODE ADDRESSING, LIMITED MODULAR FAMILY
TI SPP-9900 SERIES	TOO SLOW, TOO INFLEXIBLE, NOT MICROPROGRAMMABLE, AVAILABLE ONLY FROM A SINGLE SOURCE, NOT MODULAR.
FAIRCHILD 9400 BIPOLAR SERIES	TOO SLOW, TOO INFLEXIBLE, NOT MICROPROGRAMMABLE, AVAILABLE ONLY FROM A SINGLE SOURCE, NOT MODULAR
AM 2900 BIPOLAR SERIES**	MICROPROGRAMMABLE, FAST, AVAILABLE FROM AT LEAST 5 COMMERCIAL SOURCES, HIGHLY MODULAR
TI SN74S481 BIPOLAR SERIES**	FAST, MICROPROGRAMMABLE, NOT REGISTER ORIENTED, AVAILABLE ONLY FROM A SINGLE SOURCE, LIMITED MODULAR FAMILY
INTEL 8080A MOS MICROPROCESSOR	TOO SLOW, NOT MICROPROGRAMMABLE, TOO INFLEXIBLE
INTEL 8085 A-2 MOS MICROPROCESSOR	TOO SLOW, NOT MICROPROGRAMMABLE, TOO INFLEXIBLE
MOTOROLA MC 10800 MECL SERIES**	FAST, MICROPROGRAMMABLE, AVAILABLE ONLY FROM A SINGLE SOURCE, LIMITED MODULAR FAMILY
** BIT SLICE MODULAR FAMILIES	

Figure 4. Technology Evaluation Summary

AVAILABLE HARDWARE TECHNOLOGIES

All major hardware technologies to implement this microcomputer architectural concept are currently available. The computational complexity of real-time simulation dictates use of bit-slice microcomputer technology (ref. Tables 4 and 5).

During the analysis part of this project eight microcomputer/microprocessor modular families were investigated. Performance,

modularity, microprogrammability and availability from multiple commercial sources were the primary analysis criteria. Figure 4 summarizes the results and findings of that investigation. Of the families of modules considered, only the AM-2900 series bit slice family is capable of meeting the criteria mentioned above. High performance 32 bit microcomputer architectures can be designed and implemented with the AM-2900 series modules. Other required hardware technologies are summarized in Figure 5.

RAMS, ROMS, PROMS, EPROMS, MAGNETIC CORE	AVAILABLE IN MANY CAPACITIES WITH 3-STATE INTERFACES - 50 NS TO 1000 NS ACCESS AND CYCLE TIMES
BUSSING CONCEPTS	STATIC BUSSES APPEAR TO BE MOST APPROPRIATE, REQUIRE NO ACTIVE COMPONENTS, BUS MANAGEMENT CAN BE ACHIEVED WITH EITHER SPECIAL HARDWARE OR AS A TASK ASSIGNED TO THE CONTROL MICROCOMPUTER
PACKAGING CONCEPTS	COMMERCIALLY AVAILABLE IN MANY FORMS & CONFIGURATIONS SUITABLE FOR TRAINER DESIGNS

Figure 5. Other Required Hardware Technologies - Summary

CRITICAL TECHNOLOGY

The most critical technology required to achieve the microcomputer system architecture concept of Figure 2 is the development of the system control algorithm previously mentioned. Optimal partitioning of a given simulation task is another technology area that must be addressed to some formal degree if standard software modules are to be developed in the future,but it is not considered critical.

The multiple microcomputer system control algorithm concept (employing ATM and distributed cache) has been developed in detail under contract to NAVTRAEQUIPCEN. All system control requirements have been achieved in the development.

CONCEPT FEASIBILITY

Concept feasibility addressed both technical and cost issues for full acceptance. The conventional general purpose (GP) computer approach was described earlier in this paper. A life-cycle cost model (Figure 6) was developed and reasonable GP cost parameters were identified and derived from vendor price information. Likewise, a multiple microcomputer system concept using the same functions was synthesized and microcomputer cost parameters were applied to the same model. The cost model results are summarized in Table 7.

SUMMARY AND CONCLUSIONS

A conventional three GP computer system for a typical OFT was configured and a life cycle cost figure derived from the cost model of Figure 6. The same OFT program was partitioned in a heuristic manner by grouping related processing functions for assignment to individual microcomputers. The processing requirements of each of these functional groups were derived and compared with the capability of the several microcomputer modular families previously analyzed. Microcomputers comprised of the AM-2900 series bit-slice family provided the necessary processing and control capability. The cost component of the required number of microcomputers was determined from vendor supplied application data and price information.

An examination of the life-cycle summary of Table 7 indicates the cost effectiveness of the multiple microcomputer system approach. The functionally modular microcomputer system architecture is conceptually feasible with current technology and should be cost effective in the projected implementation and for its life cycle.

TABLE 7. OFT COMPUTER SYSTEM 10 YR. LIFE CYCLE COST SUMMARY

Conventional GP Computer System Approach	\$1,728,326
Multiple Microcomputer System Approach	\$ 896,857

CURRENT STATUS

A Phase I exploratory development contract was competitively awarded in September 1978 for research into and development of the control algorithm for this architectural concept. Included in that contract was the initial design analysis of a fully microprogrammable 32 bit microcomputer that implemented the instruction subset used in the original performance analysis and with hardware characteristics required to implement the control algorithm. The AM-2900 series modules were the basis for the design.

The control algorithm has evolved in an implementation combination of hardware, firmware, and software. This approach embodies the ATM and distributed cache concepts

to implement the virtual machine idea. The contractor has issued a final report as of September 1979 and the contract has been completed.

A sole source Phase II exploratory development contract was issued to the Phase I contractor in June 1979 to design, develop, fabricate, test, program, and deliver a breadboard to demonstrate concept feasibility of the total multiple microcomputer system concept and system control algorithm. This breadboard with a suitable demonstration problem is scheduled for delivery to NAVTRAEQUIPCEN in September 1980 for extensive evaluation.

1. Initial acquisition cost of processor hardware - C_{01}
2. Initial acquisition cost of memory hardware - C_{02}
3. Initial acquisition cost of interface hardware - C_{03}
4. Initial acquisition cost of peripheral electronics - C_{04}
5. Initial acquisition cost of peripheral hardware- C_{05}
6. Initial acquisition cost of processor hardware documentation - C_{06}
7. Initial acquisition cost of memory hardware documentation - C_{07}
8. Initial acquisition cost of interface hardware documentation - C_{08}
9. Initial acquisition cost of peripheral electronics documentation - C_{09}
10. Initial acquisition cost of peripheral hardware documentation - C_{10}
11. Initial acquisition cost of OFT simulation software - C_{11}
12. Initial acquisition cost of utility software - C_{12}
13. Initial acquisition cost of maintenance spares for processor, memory, and interface - C_{13} hardware.
14. Initial acquisition cost of maintenance spares for peripheral electronics and - C_{14} peripheral hardware.
15. Initial cost of maintenance training - C_{15}
16. Initial cost of SSA programmer orientation - C_{16}
17. Initial cost of test equipment - C_{17}
18. Life cycle maintenance cost (0-5 yrs.) hardware (processor, memory, interface) - C_{18}
19. Life cycle maintenance costs (5-10 yrs.) - hardware (processor, memory, interface) - C_{19}
20. Life cycle maintenance costs (0-5 yrs.) - hardware personnel - C_{20}
21. Life cycle maintenance costs (5-10 yrs.) - hardware personnel - C_{21}
22. Life cycle maintenance costs (0-5 yrs.) - software personnel - C_{22}
23. Life cycle maintenance costs (5-10 yrs.) - software personnel - C_{23}
24. Life cycle maintenance costs (0-5 yrs.) - peripheral electronics hardware - C_{24}
25. Life cycle maintenance costs (5-10 yrs.) - peripheral electronics hardware - C_{25}
26. Life cycle maintenance costs (0-5 yrs.) - peripheral hardware - C_{26}
27. Life cycle maintenance costs (5-10 yrs.) - peripheral hardware - C_{27}
28. Life cycle maintenance costs (0-5 yrs.) - peripheral electronics hardware personnel - C_{28}
29. Life cycle maintenance costs (5-10 yrs.) - peripheral electronics - C_{29}
30. Life cycle maintenance costs - SSA programmer re-orientation - C_{30}

Figure 6. Elements of Ownership Cost Model - Computer System

REFERENCES

1. Moore School Report 55-20, University of Pennsylvania, "Simulation of a Supersonic Fighter Using a Digital Computer."
2. NAVTRADEVCEN 594-1, "Analog-Digital Computers for Real-Time Simulation."
3. C. F. Summer and G. A. Wyndle, "An Analysis of Microcomputer Technology for Applications to Real-Time Trainers," Naval Training Equipment Center, Orlando, FL, NAVTRAEQUIPCEN IH-313, August 1979.
4. R. O. Pettus, et aux, "Multiple Microcomputer Control Algorithm Investigation," NAVTRAEQUIPCEN 78-C-0157-1, September 1979.

ABOUT THE AUTHOR

MR. CHARLES F. SUMMER has been a Project Engineer and Principal Investigator in the Computer Laboratory of the Research and Technology Department of the Naval Training Equipment Center since 1970. At the Center, Mr. Summer has been involved in applied research in computer technology and computer systems architecture for trainers and simulators. He is also a consultant in computer technology and computer architecture to various Center departments and other Navy and Army agencies. He has more than 24 years experience in the design of digital computers and their application in complex real-time systems. Prior to joining the Naval Training Equipment Center, Mr. Summer was associated with various firms such as RCA, Harris Corporation and Martin Marietta Corporation. He is a senior member of the Institute of Electrical and Electronic Engineers and the IEEE Computer Society, a member of Tau Beta Pi and a registered professional engineer in the State of Florida. He holds a B.S. degree in electrical engineering from the University of South Carolina.

DEVELOPMENT OF A LANDING SIGNAL OFFICER TRAINER

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Vought Corporation

SUMMARY

The Landing Signal Officer (LSO) Trainer, developed through an austere yet comprehensive research and development program at Vought, will provide another first in naval aviation training. It will provide simultaneous simulation training, with performance evaluations, for LSO's and pilots in a closed-loop mode. LSO on-the-job training requirements for the control of actual aircraft are eased. JP-5, aircraft flight hours, aircraft maintenance, and time in the training of an LSO are direct savings. In an era of more restrictive budgets and reduced operations, the opportunities to teach and learn aircraft control are more limited. The Landing Signal Officer Trainer will increase the training opportunities and provide a closed-loop pilot/LSO training relationship.

INTRODUCTION

One of the most demanding tasks imposed upon the navy pilot is to make a night landing aboard an aircraft carrier. To help ensure a safe landing and to aid the pilot in making his approach to the carrier is the responsibility of the LSO. His task is even more formidable in a night environment due to the few visual cues available.

Today the training and qualification of an LSO can take as long as three years and with the diminishing aircraft inventory of the future, smaller operating budgets and longer deployments, the time honored on-the-job LSO training curriculum will become more unmanageable and more costly. No other aspect of carrier aviation training has remained as static as LSO training despite the fact that, with the exception of the carrier approach itself, no other task is more demanding or complex.

Accordingly, a Landing Signal Officer Trainer utilizing audiovisual training aids has become a viable requirement and is within current state-of-the-art simulator technology. This paper (Figure 1) describes the development of a Landing Signal Officer Trainer incorporating the dynamic night visual cues, carrier platform environment, and other significant information used by LSO's in controlling aircraft recoveries.

BACKGROUND

The Vought Corporation developed the first A-7 Night Carrier Landing Trainer (NCLT) for the Navy in 1971. Two of these part task simulators were delivered to the Navy in 1972, one to NAS Lemoore, CA and the other to NAS Cecil Field, FL. Since that time the NCLT's have provided invaluable training to Navy pilots in performing night carrier landing training and in general night carrier operations. The basic NCLT, Figure 2, consists of an A-7E cockpit mounted on a three-degree-of-freedom motion system, a collimated cathode-ray tube (CRT) visual display of the carrier scene presented to the pilot, and an instructor station with repeat visual display, operated by an instructor-qualified LSO.

During the development of the A-7 NCLT, Vought engineers realized the benefit of providing the LSO platform view for the possible training of LSO's. Currently in the NCLT, the instructor LSO has a repeat visual display of the pilot's view of the carrier landing scene. Because of his experience as a carrier pilot, he can relate the visual cues of that scene, Figure 3, as if he were in the cockpit with the student, to his instructional technique. However, in the real world at the LSO platform, he uses a totally different set of cues to monitor and control the approach. Were he to have those same real world cues in

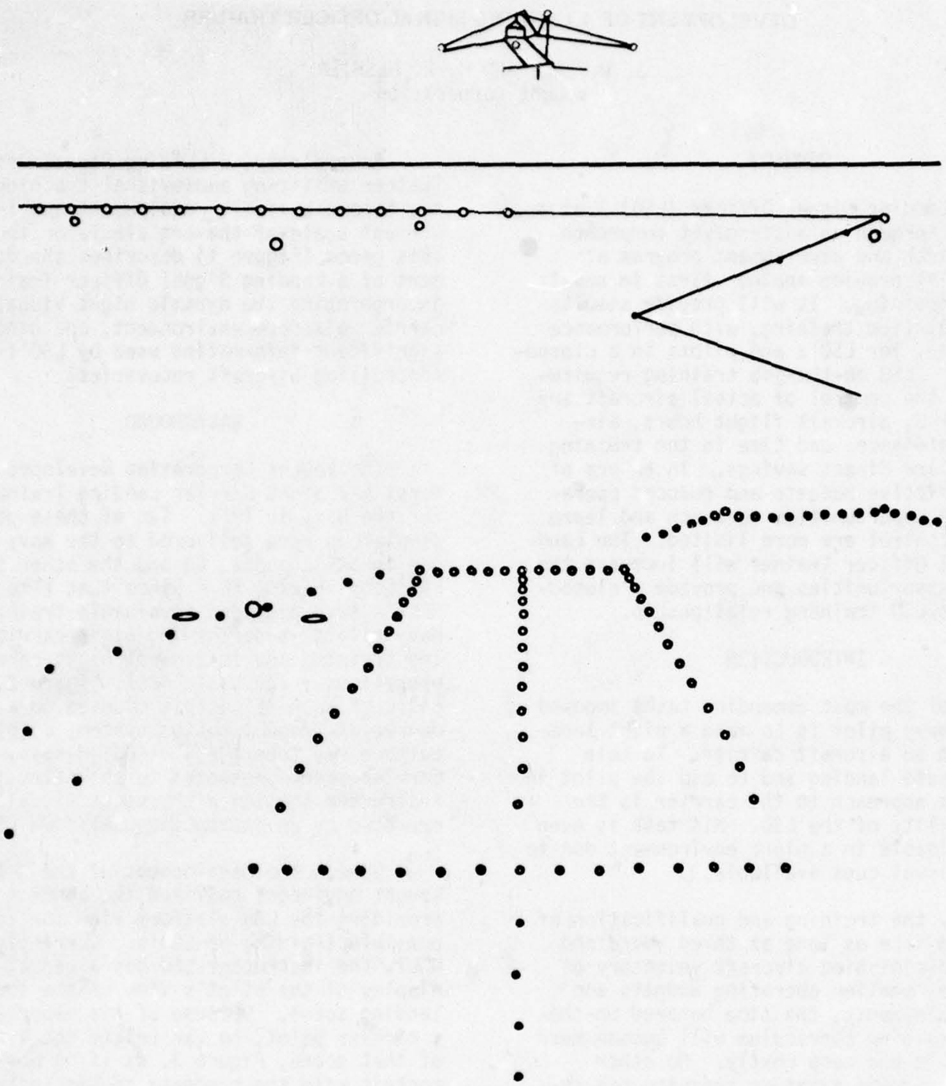

Figure 1 The Pilot/LSO Platform Scene

a simulation and use them successfully to control a simulated carrier approach, he would have a device to teach these skills to an LSO trainee.

These thoughts led to the development of a simulation to explore an LSO trainer concept (Figure 4). A simulation of a carrier landing as viewed from the LSO platform was implemented on an interactive graphics terminal. A color movie of the simulation was prepared for demonstration of the concept and shown to LSOs at the Naval Air Station (NAS) Lemoore, NAS Cecil Field, and Chief of Naval Technical Training (CNTECHTRA). The endorsement of the concept subsequently led to a concept feasibility study using the A-7E Night Carrier Landing Trainer (NCLT) in which the LSO platform view was presented on the instructor station visual display. The following paragraphs will discuss the development of the interactive graphics simulation, the concept feasibility study, and conclude with a discussion of the present development of a stand alone LSO trainer station to be incorporated into the existing A-7E NCLT facilities at NAS Lemoore and NAS Cecil Field.

INTERACTIVE GRAPHICS SIMULATION

A visual simulation of a carrier landing as viewed from the LSO platform was required to explore the feasibility of a visual training device for LSO's and to help define the requirements of such a device so that it would

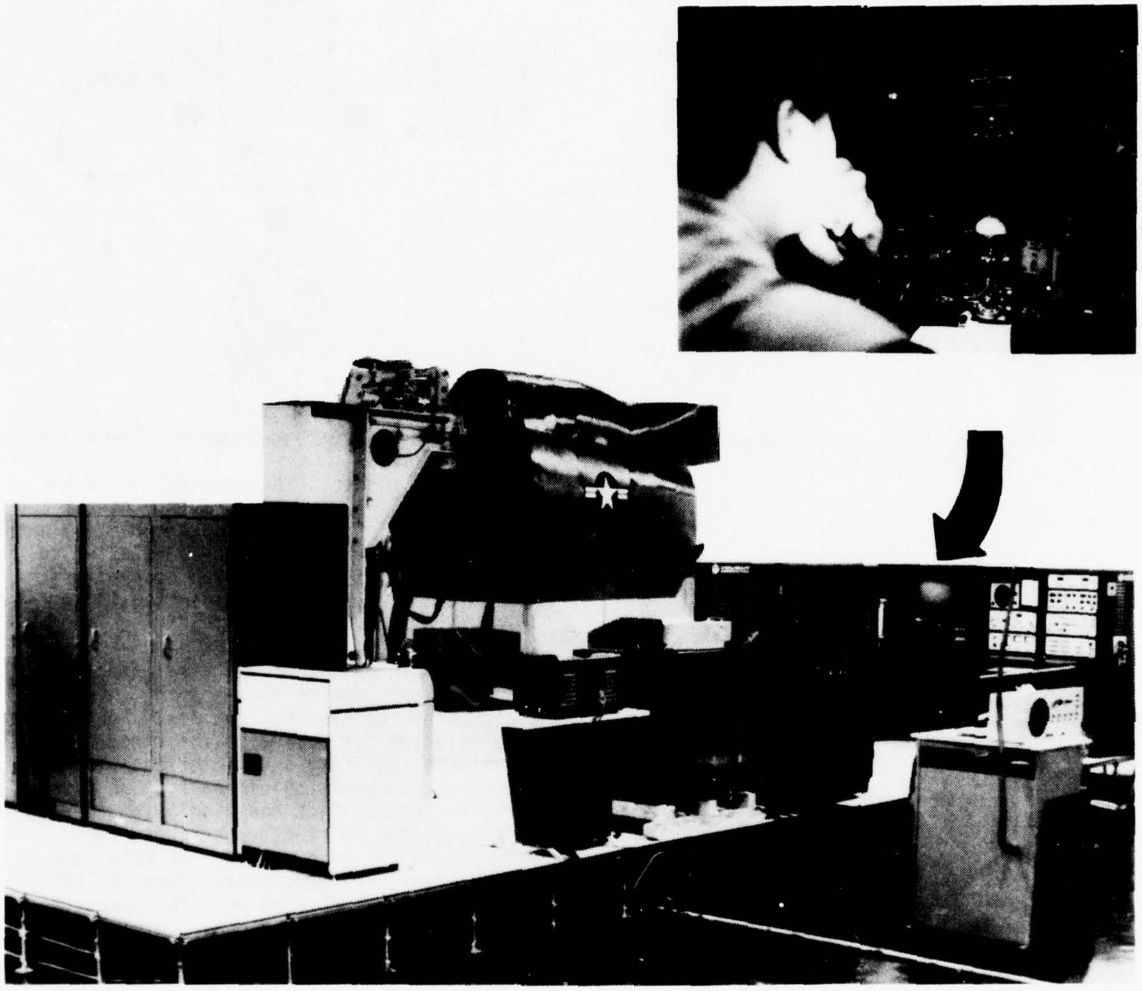

Figure 2 The A-7E Night Carrier Landing Trainer

convey maximum realism to the trainee. The philosophy in the development of the visual simulation was to provide a realistic view of an aircraft making a night landing aboard an aircraft carrier without the cost in time, hardware, and software of producing this simulation in real time. Vought's CDC 6600 computer with a CDC 274 interactive graphics system provided the key in that it could directly present a visual end display of a simulated event, generated from simple fortran routines, at a relatively low operating cost. Figure 5 shows the main components of the interactive graphics simulation. This method of simulation provided another benefit because program modifications or corrections could be made as quickly and easily as changing cards in a fortran source deck.

A vector diagram of the approach problem is shown in Figure 6. The inertial, aircraft, carrier, and LSO "eyepoint" axis systems are shown with relative position vectors and orientation angles referenced to the inertial (fixed) axis system. For the graphics simulation, the carrier orientation angles (ψ_s, θ_s, ϕ_s) were assumed zero to simplify vector transformations. This would correspond to a carrier heading of 0° (due north) relative to the inertial axis system and a calm sea state (0° carrier roll and 0° carrier pitch angle). The aircraft's position relative to the carrier and angular orientation (ψ, θ, ϕ) were provided by a time history. This requirement was fulfilled by obtaining a line printer time history which had been produced on Vought's Carrier Approach

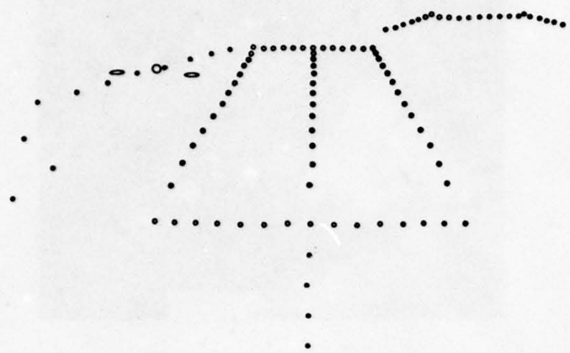

Figure 3 The Cockpit Scene

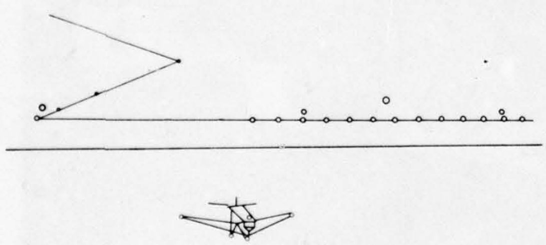

Figure 4 The Platform Scene

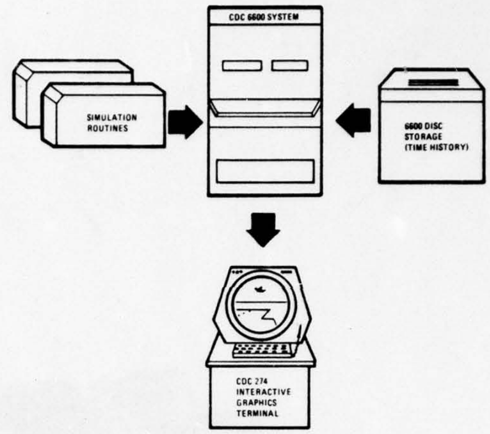

Figure 5 Interactive Graphics Simulation

Simulator. The time history presented the aircraft's position relative to the carrier axis system and the aircraft's angular orientation (Euler angles) versus time. The approach time history commenced at two nautical miles from the carrier deck and terminated at deck contact. To complete the time history, the aircraft's pitch down and roll out dynamics at wire engagement were added. A data file was then created from this time history and stored on disc in the CDC 6600 computer system (the host computer of the CDC 274 system) for use by the simulation routine. The position of the LSO eyepoint axis system is defined by a simple bias vector from the ship's axis system. The orientation of the axis system (the direction of look of the LSO "eye") is defined by an azimuth angle (ρ) and an elevation angle (γ) measured relative to the inertial axis system. The control of the direction of look will be discussed in a later paragraph.

The development of the simulation proceeded quickly due to the existing interactive graphics library routines. Routines were selected for determining the three-dimensional position and the orientation of one or more objects as viewed from an observer's reference point and displaying these objects on the interactive graphics two-dimensional CRT grid system. In this case, the observer's reference point was the LSO platform and the objects were the approaching aircraft and the carrier deck. Other routines were written to produce a model of the A-7E aircraft with wing tip, tail, and approach lights including a ghost outline of the aircraft; a model of the carrier USS Enterprise including a ghost outline of the deck and angle deck centerline lights, a horizon line, and a selectable cross-hair index for identifying the glideslope. Figures 7 and 8 show the models of the A-7E aircraft and the USS Enterprise, respectively, that were used in the simulation. The remainder of the simulation routine produced the frame-by-frame sequence of the approach utilizing the above mentioned routines and accessing the disc file for the position and orientation data of the aircraft.

To change the initial conditions and control various aspects of the simulation, two data arrays were established in the routine and displayed on the CRT. The initial conditions array provided a means of controlling the field of view of the presentation, LSO eyepoint position and orientation,

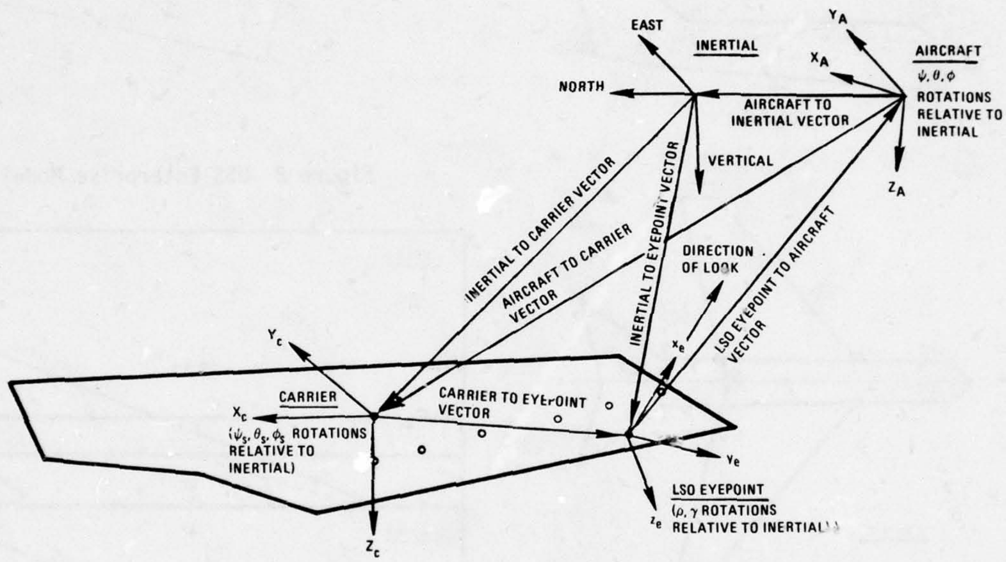

Figure 6 Vector Diagram of Approach Problems

width of the simulated CRT outline (rectangular CRT outline drawn on the graphics CRT), and a control for determining the mode of observation of the approach. The ABCDE array was used for selecting the initial and final time of an approach (for running all or part of the data file), selecting the step size at which to view the approach (i.e., every half-second, every second, etc.), selecting the brightness of the aircraft outline and horizon line, and selecting a gain for controlling the size of the approaching aircraft as a function of range to the carrier.

Four primary modes of observation, Figure 9, were programmed into the simulation by controlling the values of the azimuth and elevation angles of the LSO eyepoint axis system. Mode 1 is a staring mode in which the LSO's "eye" is held fixed in a selected azimuth and elevation. Mode 2 allows the eye to rotate in azimuth only to keep the aircraft in the azimuth field of view. Mode 3 allows the eye to rotate in azimuth and elevation to keep the aircraft in the geometric center of the CRT. Mode 4 fixes the center of the CRT on the azimuth and elevation of a point on the prescribed glideslope at the horizontal distance of the aircraft from the carrier. This gives the LSO the ability to detect lineup and glideslope errors during the aircraft approach. All modes of observation analyzed, except Mode 1, provided scene rotation to

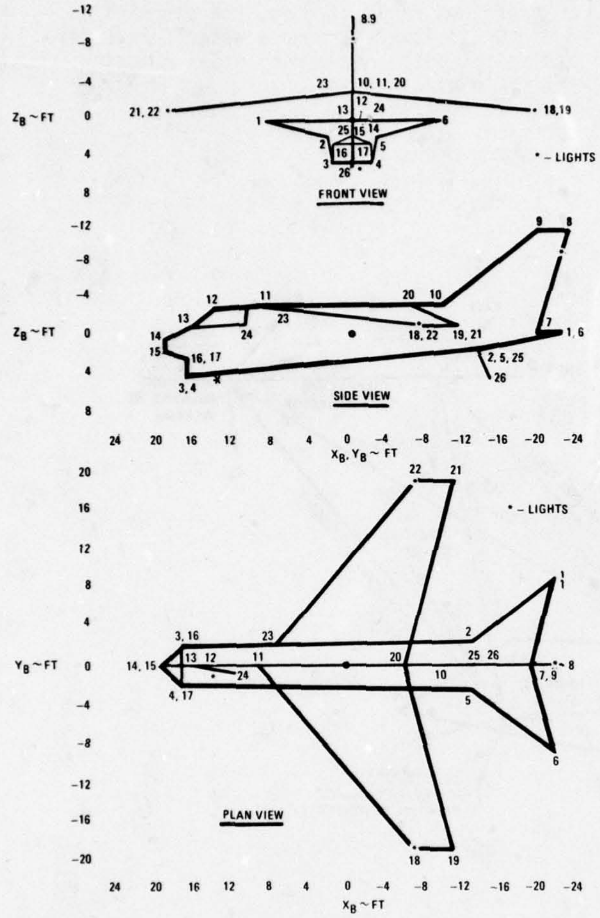

Figure 7 A-7E Model

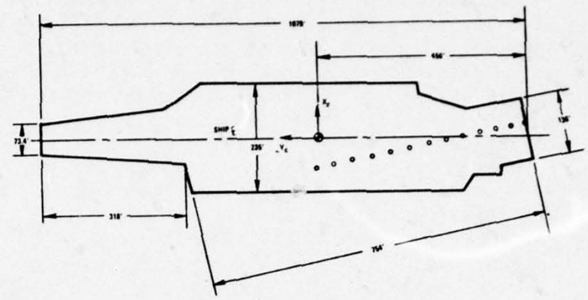

Figure 8 USS Enterprise Model

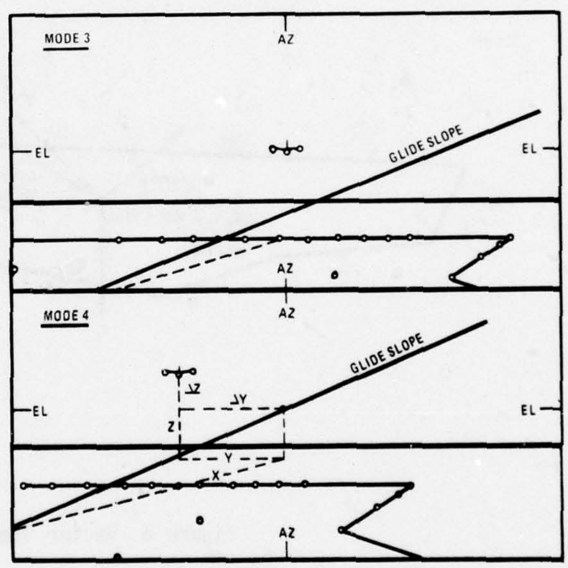

Figure 9 Platform Scene Observing Modes

allow viewing the aircraft through the entire approach.

Another important feature of the graphics system was the hard copy printout. This allowed making permanent records of various scenes of the approach as various program parameters were varied. This provided a means of comparing observing modes, fields of view, model configuration and other elements of the visual scene simultaneously. One of the primary goals of the simulation was to determine the best observing mode and the best field of view for conveying realism. The operational features of the program controlled through the data arrays provided the means of analyzing the approach in many different ways such that this goal could be met. Mode 4 at a 30° horizontal by 20° vertical field of view provided the most useful and realistic approach available from this simulation. It should be noted that although the interactive graphics system could not present a new frame on the CRT at a sufficient rate to eliminate "stepping" and in general could not maintain real-time motion, the frame rate was fast enough to make the simulation and the analysis possible.

Then, a color movie was made of the simulation. This required the ability to manually display each frame of the approach

so that a movie camera with a single frame capability could be employed. This was accomplished in the program by using the light pen key (located at the graphics console) to sequentially step through the time history data file, not just once, but as many times as there were to be different colors in the movie. The problem was to create five identical exposures for red, blue, amber, green and white colors, one frame at a time, for a two mile approach. Then,the color movie could be constructed by multi-printing an exposure for each color and adding the sound track. The time history data file stored on the disk was generated in 1/24 second intervals. Therefore, when the movie is projected at a 24-frame-per-second rate (the standard rate for 16 mm projectors) the resulting motion is in real-time. The result is a real-time simulation of the carrier landing as viewed by the LSO in color on a CRT system; the primary goal of the interactive graphics simulation (3-minute film clip).

CONCEPT FEASIBILITY STUDY

The color movie of the interactive graphics simulation was screened for the Landing Signal Officers at NAS Lemoore, NAS Cecil Field and CNTECHTRA. After a unanimous endorsement of the LSO trainer visual concept by the LSO community, Vought proposed a concept feasibility study to be performed using one of the existing A-7E NCLT facilities. By modifying the NCLT to provide the LSO platform environment, and using the basic NCLT capabilities, the LSO would be able to control simulated carrier approaches from the platform. The pilot in the NCLT cockpit would be controlled by the LSO at the platform, just as in real life. If he could do this successfully using simulated real world shipboard cues and techniques, then the merit of an LSO training station would be established. The proposal by Vought to accomplish this study was approved by the Naval Air Systems Command (NAVAIR) in November of 1976 and work was started in December of 1976.

The feasibility study required software and hardware additions to the A-7E NCLT to provide the necessary cues to simulate the LSO platform environment. The visual scene of the carrier approach from the LSO platform was provided on the instructor's station visual display while the pilot view functioned normally in the cockpit. Most of the scene content for the LSO platform view was obtained from the graphics simulation models. Also, the logic for controlling the scene orientation was obtained from Mode 4 of the graphics simulation. Although the instructor visual display (CRT) had only a 30° horizontal by 20° vertical field of view, the aircraft could be followed through a waveoff maneuver and bolter pattern entry by scene rotation. The LSO platform environment was further enhanced by providing the sounds of the approaching aircraft, as heard from the platform, using a hardware modification of the normal aircraft sound system at the instructor station and an additional speaker. The additional software modules required to present the platform visual display and provide sound system controls were assembled into the main NCLT program in the central host computer. A small electronics cabinet containing all the required hardware for the feasibility study was mounted just above the visual display on instructor's station. All new control switches required for controlling the simulation during the feasibility study were mounted on the front panel of this cabinet in easy reach of the LSO, and the additional speaker for the platform sound was mounted on top of the cabinet. The installation of the interface controls is shown in Figure 10. All basic NCLT controls were functional including weather conditions (ceiling, visibility, sea state, wind), problem FREEZE, and problem REPLAY in which all or a part of the last approach could be replayed.

The LSO platform visual-scene elements for the feasibility study included an A-7E aircraft model, carrier models of the USS Range or USS Roosevelt, a horizon line, and

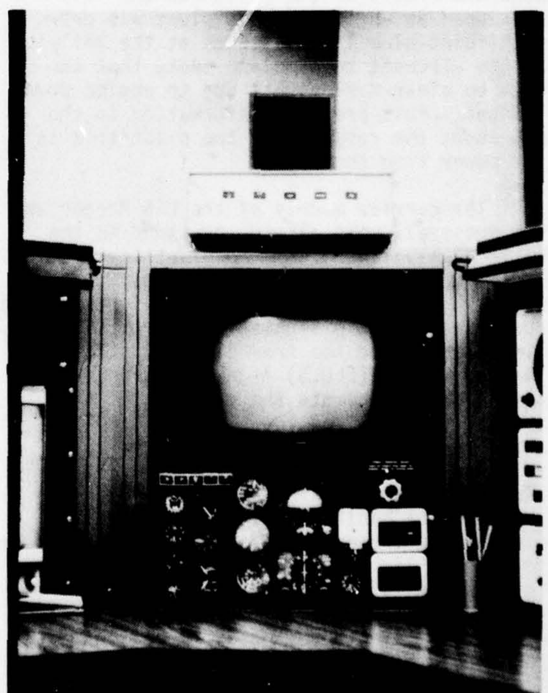

Figure 10 Interface Controller

a selectable cross hair index centered on the glideslope. A representative view of the platform approach scene is shown in Figure 11. The pilot has just been given a waveoff from the LSO and is responding accordingly. The airplane model was similar to the model used in the graphics simulation including the left and right wing tip lights, the approach indexer light, tail light, and a faint ghost outline. In addition, the model included a conditionally generated tail hook and engine exhaust plume. The red left wing tip light and green right wing tip light were displayed at all times. The white tail light was displayed when not occulted by the vertical tail. The approach light, located on the nose gear door, was displayed when the landing gear was down and could be red, amber or green depending on aircraft angle of attack. If the landing gear was down but the tail hook was up, the approach light would flash at 1 HZ. If the landing gear was up,the approach light was extinguished. All the aircraft lights increased in intensity with decreasing range to the carrier. These lights provide much of the information available to the LSO on the platform such as landing gear and tail hook position (from the approach light), approach speed (from approach light color) and distance and bank attitude from the wing tip lights. The ghost outline, including the tail hook, was drawn with a series of faint-blue line segments that increased in intensity with decreasing range to the carrier. The tail hook was erased if the pilot had the tail hook up. An engine exhaust plume was drawn with faint-blue line segments at the tailpipe of the aircraft to simulate smoke that can be seen on clear dark nights due to engine power changes. This provides information to the LSO about the response of the pilot to a call for power from the LSO.

The carrier models of the USS Ranger and USS Roosevelt were already provided in the basic NCLT software for the pilot's view. The models consist of the red deck-edge lights, white runway edge and centerline lights, white runway athwartship lights, red vertical dropline lights, and the fresnel lens optical landing system (FLOLS) lights. These models were used to generate the portions of the carrier visible from the LSO platform by using the "eyepoint" position of the LSO relative to the carrier axis system. A foul/clear light and a faint-blue deck-edge were added to the basic models to improve the platform environment and perspective. The foul/clear light can be red (foul) or green (clear) and is located at the deck's edge near the LSO platform within the LSO's field of view. This light provides information to the LSO about the condition of the landing area. If the light is red, indicating a foul deck, the LSO will wave-off the approaching aircraft. The faint-blue, deck-edge outline was

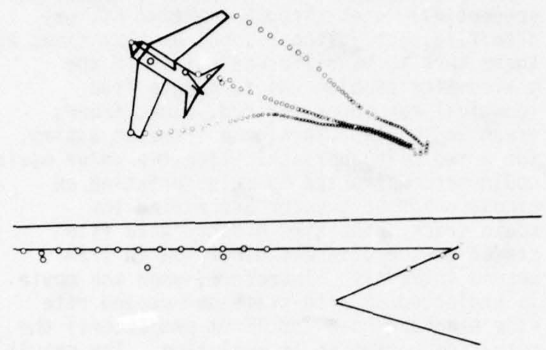

Figure 11 Platform Scene Photograph

added to better define the carrier deck surface. This was important because the LSO uses the relative position of the lights of the approaching aircraft to the deck surface in his field of view to determine whether the aircraft is high or low on the glideslope. The horizon line was drawn across the entire horizontal dimension of the visual display (CRT) with a blue line at the proper depression angle from the LSO eye. The cross-hair index was drawn as a small green plus sign that was positioned on the glideslope at aircraft range when selected by the LSO. The index provided lineup and glideslope error information since it represented the correct position for the aircraft and is envisioned as a training aid for the LSO trainee. Existing continuous controls (variable pots) at the instructor's station were reprogrammed to provide intensity control over various scene elements of the LSO platform scene including aircraft lights, aircraft outline, and the horizon line. This allowed the LSO to accurately establish the environment based on his experience on the platform.

The electronics cabinet shown in Figure 10 contained five alternate-action control switches on the front panel for controlling the instructor's station visual display. The PILOT/LSO switch presented either the normal pilot scene to the instructor LSO or the LSO platform scene. The FOUL/CLEAR deck switch controlled the color of the FOUL/CLEAR light. The PLUME switch activated the engine exhaust plume and the CROSS-HAIR switch displayed the cross-hair index. The fifth switch was a spare. If the PILOT/LSO switch was placed in PILOT position, the remaining switches were deactivated and the NCLT was returned to its

standard operating configuration. The remainder of the electronics cabinet contained the hardware required to modify the normal aircraft sound system in the NCLT. The normal system provides engine and aerodynamic sounds heard by the pilot in the cockpit. The engine sounds vary with power setting (RPM) and the aerodynamic sounds vary with aircraft speed. However, the sounds of the approaching aircraft, as heard from the platform, are attenuated as a function of range and delayed as a function of range and speed of sound. In addition, the frequency shift or doppler effect is present as the aircraft passes the LSO platform. The hardware to provide these realistic sound cues was developed by Vought's Computer Hardware Technology Department. It utilizes an electronic digital memory in the form of a series of dynamic shift registers to provide the required delay function and a separate analog multiplier to provide the attenuation effects. The output of the NCLT sound system was routed to this hardware as input without affecting the sound output to the pilot. Software equations were required to provide two digital-to-analog (D/A) signals to the hardware to control clock frequency and attenuation. The frequency equation was a function of aircraft speed, range, speed of sound, and the size of the shift register. The attenuation equation was an inverse square function of range. By controlling the digitization and shift rate of the sound input with the clock frequency equation, the delay and doppler effects are achieved. By controlling the analog multiplier with the attenuation equation, the attenuation with range is achieved. The resulting LSO platform sound was output on the speaker mounted on the top of the electronics cabinet as shown in Figure 10. This system takes advantage of state-of-the-art, low-cost electronics to provide a capability not previously developed for simulation of sound cues.

The concept feasibility study was performed on the A-7E NCLT at NAS Lemoore, in March of 1977. Vought engineers completed installation and check-out of the hardware and software additions to the existing system on March 28 and a Landing Signal Officer's conference was convened on March 29 with representatives from AIRLANT, AIRPAC, and CNTECHTRA attending. After all attendees had become thoroughly familiar with the concepts of the feasibility study, a simulator demonstration was conducted. LSO attendees were afforded the opportunity to fly the NCLT and control approaches using the platform view. Since the LSO instructor station presents only a two-dimensional display, a carrier approach was recorded and replayed on the collimated display in the NCLT cockpit. The infinity optics of the cockpit display provided depth of field and the additional dimension needed for a truly realistic display.

After the demonstration, the LSO's unanimously concluded that the LSO platform simulation very closely approximated the aircraft recovery environment from the platform, and a high degree of realism was displayed in aircraft image and performance. Furthermore, the incorporation of a stand-alone LSO trainer with collimated optics, into existing facilities, would provide excellent training for LSO's and pilots in a closed-loop mode. The Commanding Officer of Attack Squadron 122, based at Lemoore, stated in his Landing Signal Officer Conference Report of 29 - 30 March 1977 that the demonstration "clearly establishes the feasibility of an LSO trainer. The realism achieved with the limited view from one nineteen-inch, cathode-ray tube is truly phenomenal ...." The message from AIRLANT to NAVAIR regarding the simulator demonstration stated "Feasibility meeting NAS Lemoore 29 March 1977 extremely successful ... display was real and accurate. Present state of art technology makes such a trainer feasible to train LSO's ...." Similar endorsements were also provided by AIRPAC and CNTECHTRA.

LANDING SIGNAL OFFICER TRAINING STATION

The immense success of the concept feasibility study and the support and recommendations of the LSO community provided the basis for a proposal by Vought to design and build a complete LSO training station incorporating the dynamic night visual cues, carrier platform environment and other significant information used by LSO's in controlling aircraft recoveries. The LSO training station will be integrated into existing A-7E NCLT facilities at NAS Cecil Field and NAS Lemoore, utilizing maximum commonality of NCLT hardware and software. The station is light tight and soundproof, providing isolation from outside distractions (as does the cockpit for the pilot trainee) and it will provide a more realistic night shipboard environment.

During Vought's preparation for the concept feasibility study at NAS Lemoore, an in-house mockup of an LSO shipboard platform was built employing a light tight-cylindrical enclosure. The mockup included a simulated visual scene of the approaching aircraft on two dummy CRT's, an LSO shipboard console and perspective murals on the walls to simulate the angled deck landing area to the left of the platform, the carrier's deck-edge and escape net to the right, a black sky and star field above and a horizon line extended from the CRT horizon. The murals were drawn in proper relation and perspective to the visual scene within the CRT's to provide the complete visual platform environment. Various representatives from the LSO

community were invited to view the mockup and to provide their recommendations for improving the simulated station. The final configuration that evolved for the LSO training station is shown in Figure 12. The LSO's that viewed the mockup at Vought and attended the feasibility demonstration at NAS Lemoore were able to mentally place the dynamic visual scene they had used at Lemoore into the simulated station mockup and get an idea of the realism that would be afforded by the training station.

The proposed LSO training station will contain collimated visual assemblies, LSO instrument console, manual optical visual landing aid system (MOVLAS) control and indicator, sound system, LSO station control panel and simulated environmental surroundings. Two 25-inch diagonal color CRT's with collimating optics will be used to provide the dynamic visual scene. The two displays will be mounted side by side to provide a large 80^{o} horizontal by 32^{o} vertical field of view. This provides over twice the instantaneous horizontal field of view of the NCLT instructor station CRT used for the feasibility study and will provide a definite improvement in the peripheral information presented to the LSO. The visual scene content will be identical to that defined in the concept feasibility study except for the possibility of an additional carrier model. The LSO instrument console will be a duplicate of the shipboard console and can be moveable within the enclosure. The hook to ramp, wind direction and wind velocity indicators on the instrument console will be dynamic indications driven by the computer. The remaining instruments found on the console will be simulated as far as front appearance and dial lighting. The sound system, located in the training station, will provide both the sounds from the approaching aircraft and typical deck sounds. The hardware design developed during the concept feasibility study for providing aircraft sounds including delay, doppler, and range effects will be used and the deck sounds will be provided through a tape player/recorder. The deck sounds will be recorded at an actual LSO platform under normal landing conditions. The cylindrical/spherical shape of the enclosure provides the desirable shape for the simulated environmental surroundings which include a horizon, star field, and carrier deck.

With the addition of the LSO training station to the basic NCLT facility, simultaneous training of pilots and LSO's in a closed-loop mode can be accomplished. In addition, a canned approach software system has been proposed as an LSO training aid. This system will store and replay up to ten

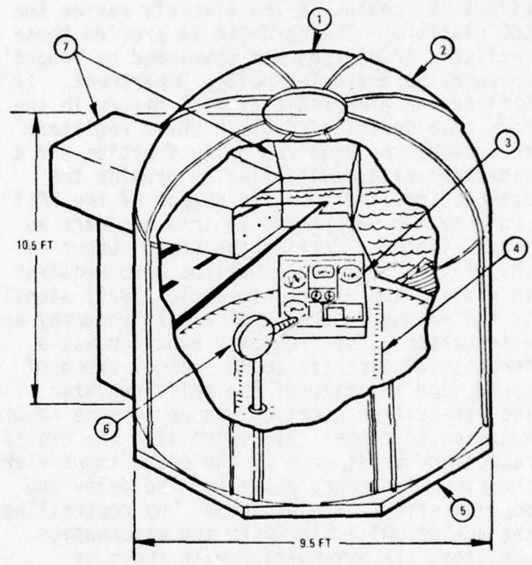

Figure 12 LSO Training Station

previous carrier approaches of 60 second duration. The LSO instructor can select any particular canned approach during an LSO training session and display the approach to the student in the LSO training station. This feature will provide independent training of LSO's without the need for a pilot in the cockpit.

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AIRCRAFT SIMULATORS: RECENT IMPROVEMENTS AND AREAS OF RESEARCH

DR. M. MCKINNON and MR. D. RAPTIS
CAE Electronics Ltd.

ABSTRACT

The aircraft simulator industry follows closely the state of the art in all the disciplines of interest in flight simulation, both commercial and military.

This paper presents recent improvement, in motion hardware and software, their interdependance as well as active areas of research and possible future trends.

INTRODUCTION

Pilot training and flight simulation are challenging and complex facets of aviation technology since a wide spectrum of engineering disciplines are employed which require state of the art design. As systems improve, more stringent performance is demanded; good maintainability and reliability are essential due to the high-utilization factors which may exceed twenty hours daily; cost and space requirements, too, provide design constraints.

As improved simulators become available, and as fuel costs rise, an increasing portion of flight training is carried out on simulators. Nearly all normal and abnormal conditions can be simulated; however, the quality of simulation is critical since inadequate or inaccurate simulation can have negative training value.

This paper is directed mainly at motion simulation, a contentious issue in simulation since by their nature conventional motion systems are limited in excursion and velocity compared to an aircraft which can move freely in air. Generally, the goal of motion simulation is to reproduce as faithfully as possible the accelerations experienced in an aircraft within the available excursions. Many existing motion systems have been designed or programmed with inherent distortions in some modes which result in improper cues to the pilot and possible negative training. The quality of the motion system and the presence of spurious accelerations or bumps also determines the effectiveness of training.

Properly implemented motion simulation can definitely enhance the realism of the cockpit environment and provide essential feedback to the pilot which will affect his interpretation of the audio, visual, instrument and control, feel information presented to him.

QUALITIES OF GOOD MOTION SYSTEM HARDWARE

Based on experience in modern simulators, the main points characterizing the quality of motion hardware are the following:

a) Smoothness - Until recently, the hydraulic actuators that moved a simulator cabin introduced a jerky movement of their own when they changed direction. This "reversal bump" alarmed pilots because it does not exist in normal flight. This distraction greatly diminished the effectiveness of the training because psychologically the pilot was not in the same environment as in the aircraft.

Lately, through the use of hydrostatic bearings it was possible to decrease the friction in the hydraulic actuators by an order of magnitude to about .3% of maximum force. Too, the servovalve was designed to maintain constant pressures on either side of the piston at constant velocity, regardless of the direction of motion, thus eliminating pressure fluctuations at turn-around, which also contributes to reversal bump. It is apparent that the valve input-output characteristics must be as linear as possible, even close to their neutral point, to avoid distortion.

Using these techniques, a reversal bump of less than .01g is achieved.

While reducing friction reduces turnaround bump, it also has the negative effect of making the system more sensitive to general noise, such as electronic pick up, pump vibrations or inconsistencies in the servovalve characteristic which are particularly pronounced in the null region; hence, the overall quality of design must be improved.

b) Time Lags - For a motion cue to be effective, it must appear as fast as it does in real life. However, the time necessary for the computer to complete its iteration cycle and the hardware to start reacting results in lag. If this lag is excessively large, the pilot might overreact and possibly start a series of pilot-induced oscillations.

The controls, visual system and sound generating system have time lags of their own. Poor coordination between them would have disruptive effects. Generally the hydraulic actuators, being bulky mechanical components, have the biggest time lag. Therefore, improvements in motion response time permits corresponding response improvements in other systems.

c) Bandwidth - The motion system must give an output of the same form as the command it receives. Thus it must have constant gain up to its maximum bandpass, which must be as wide as possible, with a minimum phase shift between input and output.

If the computed commands to the actuator are given as a series of position commands, which apparently come in steps, a high-pass system will follow these position steps accurately. This corresponds to an irregular motion, since the acceleration that the pilot feels has a series of discontinuities corresponding to the computer iteration rate. For this reason CAE has adopted the use of acceleration commands for the hydrostatic motion system. In this case the resulting motion is smoothed because we no longer differentiate twice a step command.

Position commands are used in parallel as a low-pass (and of course smoothed) signal in order to correct errors in position that would accumulate if only acceleration were used.

The bandpass used is 10 Hz, compared to 0.5 Hz in conventional systems. The limit on bandwidth is a filter used to eliminate the effects of computer iteration rate. The hardware bandwidth can be increased still further. Furthermore, it was observed that at this bandpass the movement was still extremely smooth and noise free, thus giving the impression of actually flying in the air. These achievements were realized through the use of a force servo to replace the conventional position servo at high frequencies and through improved hardware design.

Figure 1 shows the experimental results obtained with the CAE motion system.

d) Buffet Response - Several forms of high frequency buffet occur in an aircraft flying under various conditions; hence, the resulting motions must be synthesized for simulation. In cases where the frequency of the buffet exceeds the motion system bandwidth, analog buffet generating circuits bypass the smoothing filter.

e) Excursions - The physical size of a motion system is determined by a number of factors; the building size available; mechanical design constraints; as well as desired performance. From the performance point of view, a motion system ideally should have the largest possible excursions. Practically, the useable extent of excursions is determined mainly by the maximum velocity required which translates into the capacity of the hydraulic supply and the geometry of the motion actuators. The maximum velocity in turn dictates the magnitude and duration of the largest acceleration cue that can be generated. In effect a large sustained acceleration will soon saturate the velocity and excursion capabilities. Generally, in simulation of motion, only the initial onset of a sustained acceleration is simulated. Once the onset simulation subsides, the crew compartment is returned towards its neutral position at an acceleration rate below the level of human perception. This "washing out" of acceleration is the prime user of excursion and it can readily be shown that the magnitude of the worst case acceleration cue to be generated determines the required geometry. Much of the art of motion simulation lies in optimal use of the space available. The excursions shown for the Series 500 motion in Table I represent a good compromise for most cases.

f) Background Noise - One measure of performance which is crucial is the magnitude of background spurious accelerations. These include the reversal bump discussed previously, vibrations radiating from the hydraulic supply, hydraulic noise caused by the flow of hydraulic fluid through the servo valves and associated hydraulic components, computer generated noise, electronic noise and mechanical vibrations. A measure of the acceleration noise spectra for various axes, at the pilot's position is a good performance index. Incongruous as it may seem, one of the most important requirements of a good motion system is that it be capable of providing motions that cannot be sensed by the pilot. This is true for cue washout and, in addition, to sustain a feeling of being airborne. A standard technique to measure and compare motion systems on the basis of noise would be useful. Such a technique has been proposed by den Hollander and Baarspul[5].

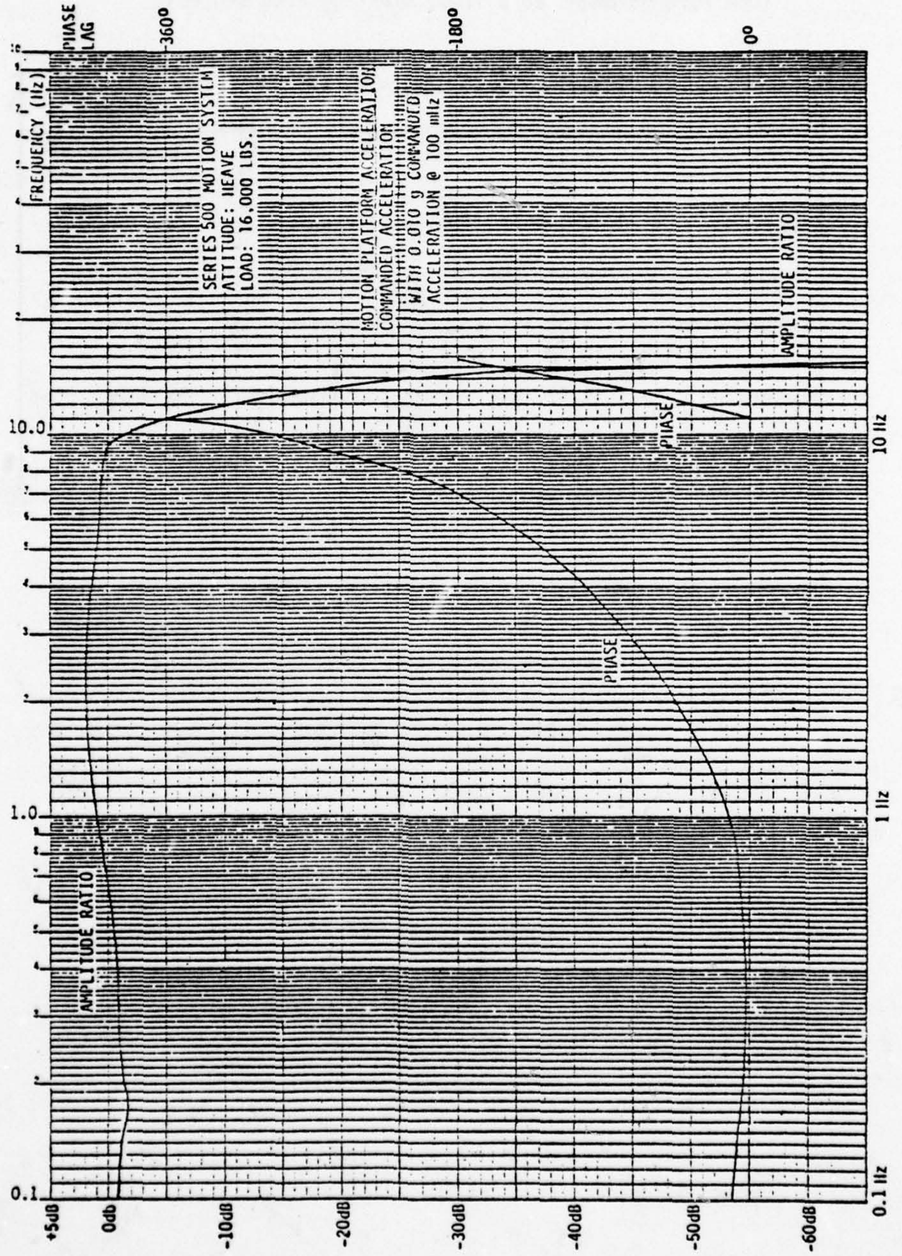

Figure 1. Motion System Frequency Response

TABLE 1

INTERMEDIATE MOTION SYSTEM LIMITS OF MOTION

(One Pure Movement at a Time, Starting From Neutral)

	Travel Limits	Velocity Limits	Acceleration Limits
Pitch	+ 37° - 32°	± 24°/sec	± 250°/sec^2
Roll	± 28°	± 24°/sec	± 250°/sec^2
Yaw	± 34°	± 24°/sec	± 250°/sec^2
Longitudinal	+ 39 in. - 49	± 28 in/sec	± 0.6g
Lateral	± 42 in.	± 28 in/sec	± 0.6g
Vertical	- 31 in. + 36	± 24 in/sec	± 1g

Basically, background noise increases with velocity and acceleration; however, it is the ratio of acceleration noise to commanded acceleration which is important since a pilot readily feels small vibrations by themselves but not if they are superimposed on a large acceleration. The most useful gauge of quality in this respect is a simple measure of peak to peak acceleration noise with a sinusoidal input and with constant velocity inputs. Spectrum analysis of the noise provides useful information as to the source of noise but is not significant in terms of quality. The plot of Figure 2 shows the signal to noise ratio of the CAE Series 500 Motion System.

MOTION SOFTWARE

The motion software is an optimal control theory problem. The constraints are given by the hardware data. The identification of the flight accelerations to be simulated and the definition of the criterion for optimality is a much more difficult task. It is also extremely important, since it sets the basis for the solution.

Traditionally the cost function approach has been the favorite tool for finding the optimum platform movement.

According to the previous discussion we can establish a cost function of the form

$$I = \int dt = [(\ddot{X}_{ir} - \ddot{X}_{is}) \frac{S + c}{S^2 + a_1 S + b_1}]^2$$

$$+ K \dot{x}_{is}^2 + \lambda x_{is}^2 \quad dt$$

whose minimum will give us the required platform accelerations. The following terminology is used:

X_{is} = any rotational or translational movement (i = 1, 6) of the platform.

$\dot{X}_{is}$ = any rotational or translational speed of the platform.

$\ddot{X}_{is}$ = any rotational or translational acceleration of the platform.

$\ddot{X}_{ir}$ = the corresponding acceleration demanded by flight.

The term $\frac{S + c}{S^2 + a_1 S + b_1}$ for translation or $\frac{1}{S^2 + a_2 S + b_2}$ for rotations represent a model of the human sensory system [1] . The term $[(\ddot{X}_{ir} - \ddot{X}_{is}) \frac{S + c}{S^2 + a_1 S + b_1}]^2$ represents the penalty of not supplying the acceleration demanded and the other term penalties for having to use speed and displacement to achieve this acceleration. Finding the optimum X [4] enables us to simulate as closely as possible, according to a pilot's point of view, the real motion.

ANALYSIS OF PILOT BEHAVIOUR

The pilot manipulates the controls, sees the instruments and the visual simulation, hears the sound and applies the control input according to the information fed back to him. For this reason only the cue onset after a certain control movement is important, the long term motion effects being disregarded.

The motion platform alone is usually sufficient for commercial applications. However, for military applications the G-seat, the G-suit, the seat belt and the helmet loader have some additional value, although the high-g area is still far from accurately represented.

Defining a mathematical model that represents the way a human being feels is a very complex task. Several models, however, are accepted as reasonably accurate for some simple cases [2]. Apart from the complexities involved in the flight environment it must also be remembered that experience makes a pilot sense motion differently than a layman, because he subconsiously concentrates on the cues that are important to These cues must be singled out, analyzed and provided in the simulator for a satisfactory representation.

It is possible that a good analysis of the mechanism of the human system will lead to the case where the motion cue will be fed to the brain without moving the body. The impression of rotation, for example, may be created by stimulating the vestibular system using a flow of water into the ear whose temperature varies [3]. Although such methods are still experimental and of an interest much wider than simulation of motion, they will hopefully enable us to simulate the high-g cues of the military and aerospace aircraft.

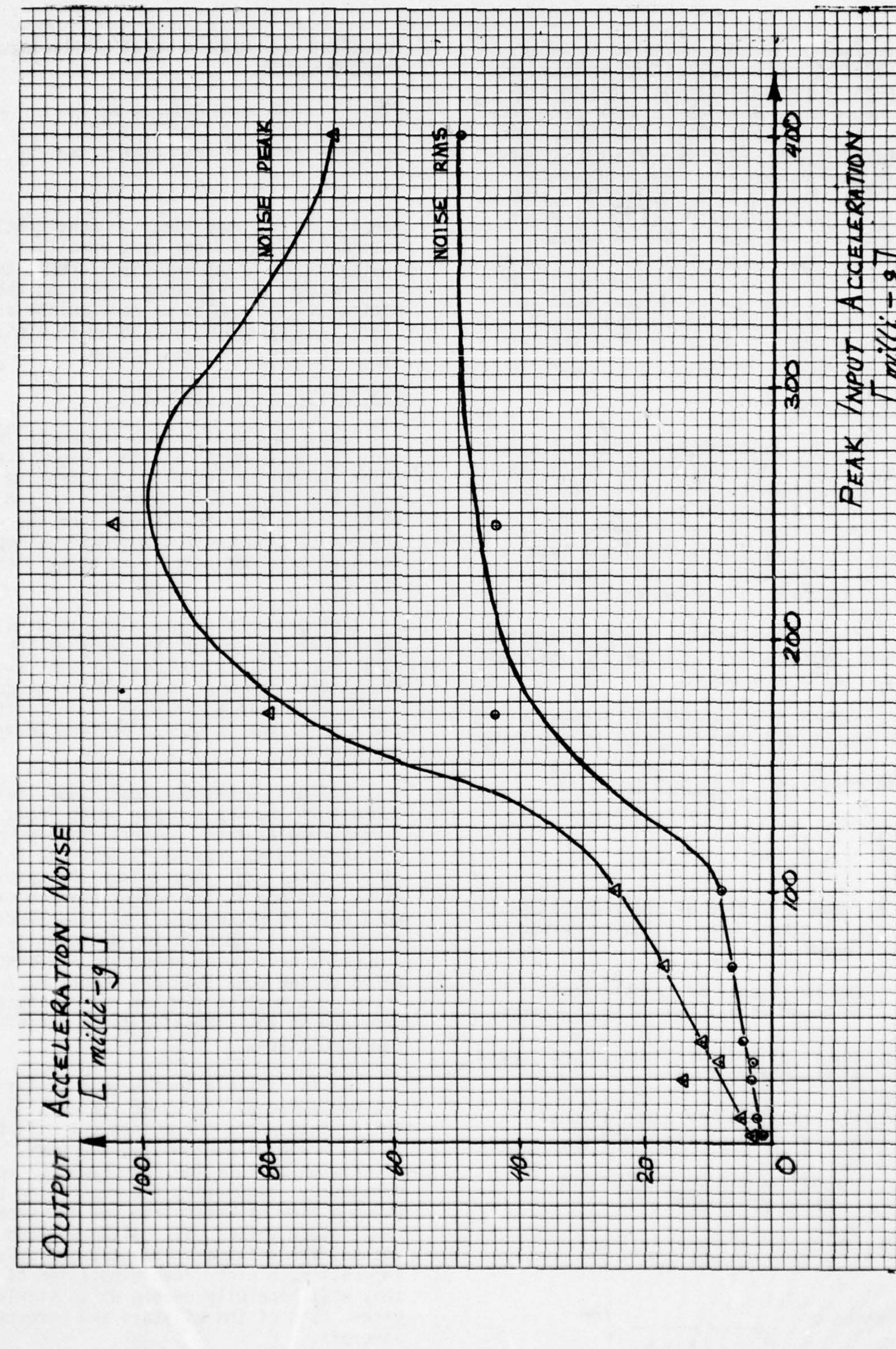

Figure 2. Signal to Noise Ratio of the CAE Series 500 Motion System

CONCLUSIONS

The simulation of motion has been greatly improved by the use of hydrostatic actuators with a 10 Hz passband that eliminates high frequency noise. The system is controlled mainly by acceleration commands. The software takes into consideration human modelling and the hardware constraints. The use of g-seat and seat belt is a useful addition for military applications.

Some measures of performance have been provided with data from the CAE Series 500 motion to provide a standard for quality comparison.

REFERENCES

1. Hosman, R.J.A.W. and Van der Vaart, J.C. "Thresholds of Motion Percention Measured in a Flight Simulator"; Twelth Annual Conference on Manual Control, University of Illinois, May 1976.

2. Young, L.R. "The Current Status of Vestibular System Models"; Automatica Vol. 5, 1979, p.p 369-383.

3. Demers, R. "Analysis of Human Vestibular Responses to Caloric Simulation"; Ph.D. Thesis, McGill University, May 1975.

4. Raptis, D. and McKinnon, M. "Recent Developments in Flight Simulation Techniques"; Tenth Annual Conference on Modelling and Simulation, University of Pittsburgh, April 1979.

5. den Hollander, J.G. and Baarspul, M., "Measurement of the Motion Quality of a Moving Base Flight Simulator", Delft University of Technology Memorandum M-264, Jan. 1977.

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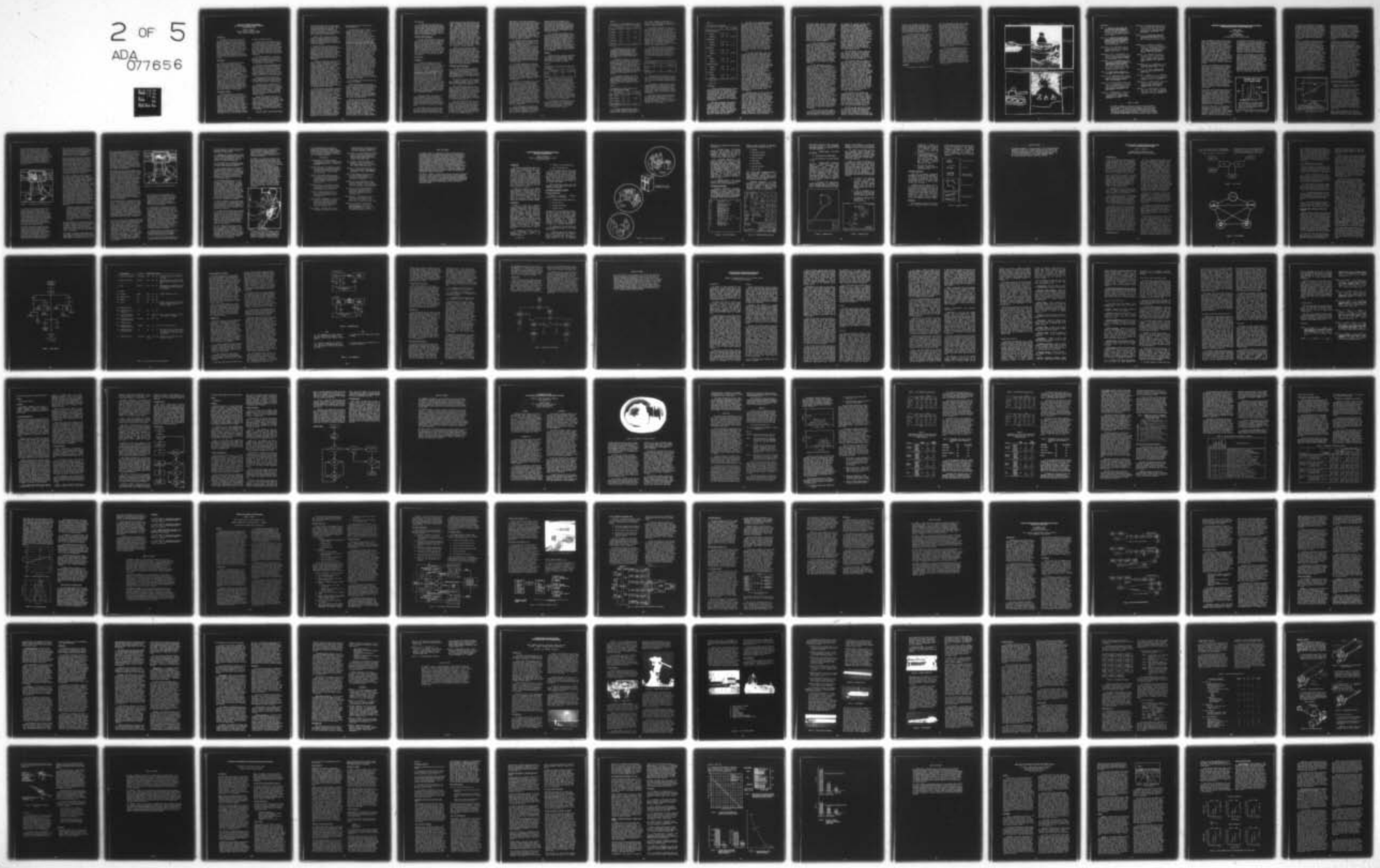

IMMEDIATE LEARNER ACHIEVEMENT AS AN EFFECT OF AESTHETIC EMBELLISHMENT IN EDUCATIONAL ART

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INTRODUCTION

The purpose of this study is to determine the effects of levels of artwork in audio-visual sound-slide teaching devices on message comprehension. More specifically, the experiment was undertaken to determine whether a student can obtain as much information from simple art (line drawings, stick figures, geometric patterns, etc.) as he can from a more complex rendition of the same subject, including full human figures, extremely detailed subject matter, use of color and more embellishment for the purpose of intensifying the aesthetic quality of the visual.

THE PROBLEM

The U. S. Army Combat Arms Training Board initiated an audio-visual TEC (Training Extension Course) program in 1972. The first TEC lesson was ready for field use in 1974. The typical TEC lesson includes a filmstrip cartridge and an audio cassette that are designated for synchronous use in the Beseler Cue/See projector. The filmstrip is produced by photographing commercially developed artwork. A TEC lesson normally contains approximately 150 pieces of art. The current cost of one frame of art may vary from as little as 15 dollars for a simple piece to as much as 75 dollars for a complex piece. If a simple drawing could achieve the same results as a complicated embellished art frame, the Government would realize substantial savings in money as well as in time invested in developing and producing TEC lessons for this program.

CONTRIBUTORY STUDIES

The justification for using large amounts of realistic detail in visual illustration is found in the theoretical work of Morris (1946), Carpenter (1953) and Dale (1954). Although differing considerably in detail, these various theoretical orientations can all be classified as realism theories (Dwyer, 1972). The basic assumption underlying all of these theories is that learning will be more complete as the number of cues in the learning situation increases. Therefore, an increase in realism in the visual portion of the lessons would increase the number of cues in the learning situation, thereby facilitating learning.

Bullough (1974) discovered that most media designers have been content to forget about the problem and to use embellishments in a rather random or accidental fashion. Aesthetics in media design are often thought of as additional effects that actually may not assure greater increments of learning. However, Bullough suggests that the student's innate sensitivity to appealing displays be considered.

Ball (1960) suggested it is entirely possible that both too much or too little aesthetic embellishment in educational art could detract from the student's capability to comprehend the subject matter.

Few studies have been conducted which investigate the relative effectiveness of visual illustrations that employ different amounts of realistic detail to complement oral instruction. Two important early studies (Carpenter, 1954; Lumsdaine, 1958) employed filmographs to study simple versus complex motion picture film presentations.

Carpenter concluded that simplified visual presentations in the motion picture format compared with more complex ones did not differ significantly in effectiveness.

Lunsdaine (1958) replicated the filmograph experiment using a motion picture entitled "The Cowboys" and still photographs taken from the original film. His subjects were fourth and fifth graders. Lumsdaine concluded there was no significant difference in achievement gains between the two treatment groups.

Gorman (1973) employed two black-and-white slide presentations to study the effects of pictorial detail on concept formation. One set of slides employed simple line drawings while the other set employed detailed drawings. He selected 150 fifth, ninth, and 12th-grade students for subjects in his study. There were no significant differences in the final performance of any of his groups.

Spaulding (1956) studied the performance

of poorly educated adults in several countries and found that they had difficulty in interpreting complex illustrations. He concluded that pictorial complexity may reduce the "readability" of a picture in much the same way that idea density reduces the readability of printed material.

Wicker's (1970) research on paired-associate learning and the work of Paivio, Rogers, and Smythe (1968) on free recall showed that detailed pictures did not significantly improve learning as compared with simple line drawings.

Perhaps the most significant work in this area is a series of studies carried out by Dwyer (1970). He points out that the effectiveness of visualized instruction relative to student achievement is primarily dependent upon the type of visualization, the method or mode of presentation, the learning objectives, characteristics of the target audience and attention-focusing techniques.

An important observation resulting from Dwyer's studies is that where the use of visuals did make a difference in increasing student achievement, those illustrations containing relatively small amounts of realistic detail were most effective. These results were attributed to the fact that students viewed their respective types of visuals for equal amounts of time. In contrast, results of the self-paced studies indicated that where the use of visuals did make a difference in increasing student achievement, the more realistic illustrations were most effective. These results were explained by the fact that students were permitted to interact with the more realistic illustrations for as long as they felt necessary to complete their understanding of the information being processed.

The most recent study conducted regarding amount of realism in instructional visuals was carried out by Borg (1977). The experiment was conducted for the U. S. Army Research Institute at Fort Eustis, Virginia and was directly related to the U. S. Army's Training Extension Course (TEC) program. These audio-visual lessons have been designed to eventually cover every MOS (military occupational skill) offered by the Army. Most TEC lessons are self-paced and require an occasional immediate decisive response from the student. Other TEC lessons are designed to teach the soldier a task or tasks with a continuous flow of information. These are scored by a post-test. TEC is generally used as supplemental or support training but in some cases it is used for primary training. The programs are mainly designed for use with enlisted soldiers whose average education approaches the ninth-grade level.

The target population for Borg's research was Armor Crewmen. A total of 80 subjects with this primary MOS were randomly assigned to four groups. Two of these groups were administered the complex version of the selected TEC lesson while the other two groups were administered the simple version. The TEC lesson selected for the test was entitled, Bore Sighting the Machineguns, M60/M60A1 Tank. The lesson had been developed and produced by the U. S. Army Armor School at Fort Knox, Kentucky and was already in use in the field. It consists of an audio tape plus a filmstrip containing 119 visual frames. These visuals included nine which were classified as simple artwork, 34 classified as standard artwork and 70 classified as complex artwork. In order to develop a simpler version of the lesson, the investigators analyzed each frame in the complex lesson and prepared specifications for simplifying most of the frames. This process resulted in 38 simple frames, 59 standard frames and 16 complex frames. Much of the simplification involved removing superfluous items such as foliage in the foreground and mountains, trees, etc. in the background, removing hands from the equipment, removing uniform details from soldiers depicted in the frames and sketching equipment rather than drawing it to scale. Both lessons employed the same audio tape which was inaudibly pulsed to advance the filmstrip automatically and required the same amount of time to complete, approximately 35 minutes.

Each treatment was carried out with two groups of 20 subjects.

Test measures employed for the study included a 36-item pre-test which dealt with specific content covered in the selected TEC lesson. Afterwards, a 36 item post-test was administered which closely paralleled the pre-test in terms of item content although the specific items used in the two forms were different. A visual achievement test and an attitude measurement questionnaire were also administered.

Analysis of covariance was employed to analyze the results of this study. For all four of the dependent variables, the differences between the adjusted final mean scores for subjects in the simple versus complex treatments were extremely small and rendered insignificant. These results prompted Borg to conclude that the complex art contributed nothing to either learning or soldiers' attitudes. Further, he expressed doubts that the complex format would be superior for any content covered in

TEC lessons.

In light of his findings, as well as the Army Research Institute's calculation that the simple version of the lesson saved one third of the total cost, Borg recommended that as high a percentage of simple art as possible be employed in the development of future TEC lessons.

PURPOSE AND HYPOTHESIS

It was this author's intention to produce an even further simplified version of the TEC lesson which was used in the Borg study. The experiment was designed to test the null hypothesis that there would be no significant difference in the achievement of subjects who are taught the same concepts using two sets of visuals which differ in detail, complexity, accuracy of scale and use of background.

METHODOLOGY

MATERIALS

It was the author's desire to duplicate the Army Research Institute's study of TEC art as closely as possible. Therefore, the materials used were two Beseler Cue/See projectors, an original complex version of the TEC lesson, Boresighting the Machineguns: M60/M60A1 Tank, a simplified version of the same lesson created by the author, plus 20 questions selected from the post-test questionnaire which had been used in the Army Research Institute study. These questions were indicative of the original 36 questions, so 20 questions were selected due to time constraints. In addition to the questionnaire, two opinion items were included. In the University of Central Florida portion of the study, six semantic differential scales were substituted for the two opinion measurement scales.

This particular TEC lesson is not self-paced in the traditional sense that the student proceeds at his own pace. This lesson is one in which the information is provided in a continuous flow and learner achievement is usually measured by a post-test.

The simple version of the filmstrip was created by projecting the original lesson on the Beseler Cue/See and free-hand drawing each frame of art onto a plain white 8½" by 11" sheet of paper using black felt tip pens. An average of five minutes was spent executing each frame of simple art. Some color was arbitrarily added to certain frames that obviously contained so many black lines that they were confusing. Some color was necessary to portray some measure of depth or perspective. Colors were selected on a random basis and were purposefully used inconsistently. For example, if blue were used for a background or to highlight an area of a visual, then red may have been used the next time that same visual came up in the lesson. In all cases, color was limited to light shading.

After the 119 simple frames of art were accomplished, they were photographed on super 8mm film using a single frame super 8mm camera, tripod, and two photo-flood lamps. The lesson was photographed three times on the same roll of film and exposure was bracketed to insure at least one projectable copy. After having the film processed, a suitable copy was selected and loaded into a super-8mm Technicolor Magi-cartridge.

SUBJECTS AND PROCEDURES

In order to maintain integrity with the Army Research Institute's study, the target audience for this experiment was selected from a U. S. Army Reserve unit in Orlando, Florida. The soldiers in the unit primarily held transportation MOS's.

Thirty-one subjects participated on a voluntary basis. These soldiers were randomly assigned to two groups designated simple and complex.

The testing took place at the Reserve unit's headquarters on a Saturday afternoon during the regularly scheduled monthly drill. The test was administered in the small-group mode (rear screen projection). The two treatments were administered simultaneously in the same room, thus controlling for possible biasing effects of intrasession history.

The two Beseler Cue/See projectors were set up back to back in the center of the room where the group on either side could not see the other screen. The subjects were told that due to the small size of the Beseler Cue/See screen, it would be necessary to split the groups and use two projectors for a better viewing

atmosphere. Since the same audio tape was used to advance both visuals, the subjects thought they were viewing the same film. After viewing the 35-minute lesson, the subjects completed the 20-item comprehension test and the opinion questions. Finally, the subjects in both groups were briefed as to the real reason for the test. Two participants, one from each condition, dropped out during the treatment. Thus, 29 subjects completed the dependent measures.

To further enhance the validity of this study, it was decided to repeat the experiment at the University of Central Florida using three freshman speech classes. In this experiment, a control group was added. Twenty-four students in one class took the complex treatment. Eighteen students in another class were given the simple treatment and 20 students in the third class were utilized as a control group which received only the 20-question questionnaire. All treatments were administered on the same day during regularly scheduled class periods.

The same independent variable, degree of realism, was used for the UCF experiment. However, in order to further determine subjects' perceptions of the two levels of art, six semantic differential scales replaced the opinion questions used in the Army sample. These included evaluations of the degree to which the lesson was sophisticated, complex, adequate, appealing, effective and interesting.

Testing of the complex group was accomplished in the Humanities and Fine Arts building in a classroom which had all outside light opaqued out. Using the Beseler Cue/See in the large group mode (projected image), the complex version of the TEC lesson was projected to a two-by-three-foot image on a standard classroom screen located in the corner of the room. After viewing the lesson, the questionnaire containing the 20 questions and six semantic differential scales was completed by each subject. The students were then briefed as to the nature of the study and the test they had just completed.

In the following class period, the simple treatment was administered in another classroom. This room was virtually identical to the first and again, all outside light was opaqued during the treatment. The subjects were given the same instructions as the complex group and the lesson was projected the same as before in the large group mode. The subjects were then administered the questionnaire and six semantic differential scales.

The control-group session followed in the next class period. Since no treatment was administered, the semantic differential scales were not used. The only task required of the control group was to complete the 20-item comprehension test. The students were allowed ten minutes to answer the questions, after which the purpose of the study was explained. As in the Army sample, all treatments in the UCF sample were administered by the author.

RESULTS

A two-tailed t-test was employed to compare the comprehension means obtained in the Army Reserve simple and complex treatments. Results of this test are shown in Table 1.

Table 1

Comparison of Army Reserve Comprehension Means

	$\overline{X}$ incorrect	df	t value
simple	13.3	28	
complex	10.9	28	1.48

Results show the simple group averaged 13.3 incorrect answers out of 20 questions while the complex group averaged 10.9 incorrect answers out of the 20 questions. While the t-test revealed no significant difference, there is an observable trend in favor of the complex treatment ($p < .20$). The data very tentatively supports the null hypothesis of no significant difference in achievement gains of subjects who are taught the same concepts using visuals which vary in amount of detail, complexity, realism and use of background.

A two-tailed t-test was also employed to compare the comprehension means obtained in the University of Central Florida experiment. The results of this test are shown in Table 2.

Table 2

Comparison of UCF Comprehension Means

	$\overline{X}$ incorrect	df	t value
simple	10.1	41	
complex	11.4	41	1.03
simple	10.1	37	
control	16.7	37	7.28*
complex	11.4	43	
control	16.7	43	6.36*

*$p < .01$

The University of Central Florida experiment revealed the simple group averaged 10.1 incorrect answers out of 20 questions and the complex group averaged 11.4 incorrect answers. Again, the t-test did not yield significance ($p > .30$).

The means between the control group and both the simple and complex groups were measured. The control group averaged 16.7 incorrect answers out of 20 while the simple group averaged 10.1 incorrect. The t-test reveals significance of $p < .01$. The t-test between the means of the control group and the complex group also produced significance at the .01 level.

Two-tailed t-tests were also used to examine differences in the comprehension levels between the Army Reserve and the UCF subjects. Table 3 contains a summary of this analysis.

Table 3

A Comparison of Army Reserve with UCF Comprehension Means

	$\overline{X}$ incorrect	df	t value
UCF simple	10.1	32	
Army simple	13.3	32	1.83*
UCF complex	11.4	38	
Army complex	10.9	38	0.02

*$p < .025$

The UCF group scored significantly higher than the Army Reserve group in the "simple" condition ($p < .025$). However, there was no significant difference between the means of the Army Reserve complex and the UCF complex groups.

A question designed to measure the Army Reserve subjects' opinions of the sufficiency of the visuals required a "yes" or "no" answer. Ten out of 14 in the simple group thought the visuals supported the lesson while 13 out of 15 in the complex group thought the visuals supported the lesson. Chi-square results revealed no significant difference of opinions between the simple and the complex groups as to whether the visuals were sufficient to support the lesson (χ^2=2.19).

An additional opinion question was included on the Army Reserve questionnaire to determine the subjects' perceptions of the quality of the artwork, regardless of whether or not it supported the lesson. Results of the test are presented in Table 4.

Table 4

Army Reserve's Opinion of the Quality of the Artwork

	$\overline{X}$	df	t value
simple	5.3	28	
complex	7.7	28	2.92*

*$p < .01$

The simple group mean was 5.3 on the 10-point scale. The complex mean was 7.7 on the 10-point scale. A one-tailed t-test revealed significance of $p < .01$.

The semantic differential scales administered to the UCF groups solicited information concerning six different points in the artwork as well as in the overall lessons used in this experiment. The opinion data is shown in Table 5.

The one-tailed t-tests revealed no significant difference on four of the measures. The complex art received significantly higher ratings on the sophistication ($p < .01$) and adequacy ($p < .05$) scales.

Table 5

UCF Opinions on Artwork

	$\overline{X}$	df	t value
Sophistication			
simple	2.64	41	
complex	4.13	41	2.45**
Complexity			
simple	3.70	41	
complex	4.60	41	1.37
Adequacy			
simple	3.35	41	
complex	4.39	41	1.74*
Appeal			
simple	2.35	41	
complex	2.52	41	0.29
Effectiveness			
simple	2.82	41	
complex	2.70	41	0.18
Interest			
simple	2.70	41	
complex	2.17	41	0.96

*$p < .05$

**$p < .01$

DICUSSION

The null hypothesis which stated there would be no significant difference between the achievement gains of subjects who are taught the same concepts using two sets of visuals which differ in detail, complexity, accuracy of scale, and use of background was supported in two separate experiments.

The same treatment was administered to two distinctly different target audiences. The Army Reserve group was used to approximate the constituency of the groups used in the Borg (1977) study. The FTU group was included to collect supplementary data, particularly regarding opinions toward the artwork.

Two additional dependent measures were employed in the Army Reserve experiment. The simple "yes" or "no" question asked the subjects their perceptions of whether the visuals were sufficient to support the lesson while the 10-point attitude scale asked the subjects to rate the quality of the artwork regardless of whether it supported the lesson or not. Interestingly, both the simple and the complex groups thought the visuals were sufficient to teach the lesson, although the attitude scale results revealed a significant difference in opinion of the overall appearance of the artwork. In other words, both groups agreed they could learn from the simple artwork even if they did not like it as well as the complex artwork.

In the UCF experiment, only two of the six additional dependent measures reached levels of significant difference. These two were the subjects' perceptions of whether the artwork was sophisticated and whether it was adequate to teach the lesson. The results of the question of adequacy were similar to those received from the Army Reserve. Even though the UCF subjects achieved approximately the same measure of immediate retention on the two treatments, they differed significantly in their perceptions pertaining to quality or adequacy of the visuals. Regarding these findings, one must consider Bullough's (1974) statement concerning the subject's innate sensitivity to appealing displays even though this research may indicate that appeal is not absolutely necessary. In support of this, Dwyer (1972) stated that the type of visuals that subjects themselves perceive as being most effective are not always the ones found to be most effective in facilitating their achievement.

Although there was no significant difference between the simple and complex groups concerning their opinions on complexity, appeal, effectiveness and interest, it must be pointed out that both UCF groups rated these items in the lower to neutral categories. This means that the FTU groups found neither the simple nor the complex TEC lessons very captivating. Since the lesson was originally designed and intended for the use of U. S. Army Armor Crewmen, this result is not surprising. This lesson was number three in a five-part series and probably contains little interest

value for anyone except a professional soldier whose job is to drive and maintain a tank. In sum, the comprehension data suggest that when the student has low to moderate interest in learning the material, the complex artwork does not significantly improve learning. It seems unlikely that the results would be different with soldiers who are assigned to Armor, and are highly motivated to learn the material regardless of the level of art embellishment.

It must be pointed out that the simple visuals created by the author were very loosely drawn; almost to the point of being extremely crude. It is not expected that the Government, nor any other institution, would opt to use artwork drawn to this extreme. However, if the simple artwork were more tightly rendered by a professional artist, it is expected that there would be even less significant difference in teaching effectiveness and learner achievement between the simple and complex artwork.

In the comparison of Army Reserve and UCF comprehension means shown in Table 3, the two simple treatments reflect a t value of 1.83 which results in a significant difference of $p < .025$. This finding may be explained by the assumption that college students have attained more of a learned sensitivity to abstract forms and representations than have enlisted Army Reserve soldiers. There is also the fact that college students have more "practice" at attentiveness since they spend a greater percentage of their time in an academic or learning environment. College students may also be able to use the audio stimulus to a greater advantage than Army Reserve soldiers because of the academic environment. This would assist the students in interpreting the associated visual cues of the lesser defined art. There was no significant difference in comprehension between the Army and UCF students who received the complex treatment. In the complex treatment, there were no abstract forms to contend with. The art was very graphic and realistic and left little doubt as to how it should have been interpreted.

The fact that the Army sample rated the complex artwork higher in quality than the simple artwork was not surprising. It is likely that the complex art earned a higher rating because it appears more professional and more symmetrically pleasing to the viewer's eye. This also explains the differences obtained from the UCF subjects' opinions regarding the questions of sophistication ($p < .01$) and adequacy ($p < .05$). Here, the complex art was rated significantly higher than the simple art. Neither of these results were surprising for these two questions closely approximated the question of quality discussed in the Army Reserve study. The lack of significant difference regarding four of the six opinion factors in the UCF data is consistent with the null findings in the comprehension data.

An implication of the study was that such a finding could considerably reduce the costs of producing audio-visual materials. As will be explained, the cost savings found in this study were quite dramatic.

The original complex artwork for the TEC lesson used in this experiment cost the Government $6,661. The simplified version of the same lesson used by Borg (1977) cost $3,949. This appears to represent a 40 per-cent savings. It must be explained, however, that before a lesson gets to the stage of development where it actually goes into the artwork process, there must be a considerable amount of "front-end" analysis in order for the artist to plan what to draw. The cost for the front-end analysis of the TEC lesson used in this study was approximately $2,000. This means the actual cost of the art used in the original complex lesson was around $4,661. The Borg (1977) artwork cost $1,949 over the cost of the front-end work. This is a savings of $2,712 from the original complex artwork.

The entire set of simple art frames created by the author cost approximately ten dollars. As this research has shown, the lesson taught approximately as well as the original $6,661 complex version. Adding the $2,000 front-end analysis cost, one still realizes a savings of $4,651 over the original lesson and $1,939 over the Borg simplified version.

Concerning the question of time, it took the artists who constructed the original lesson approximately three to four months to create the artwork. Borg's version took about two months to create, but the artists were

working from already prepared material. His artists did not actually have to conjure up a drawing. They merely reduced the complexity of actual frames of art by removing details from the integral scenes.

It took the author four hours to construct the simple lesson used in this study. However, the author was also working from the previously prepared material. Using personal experience in this field as a guide, the author estimates that a lesson could be produced in a minimum of from two to three weeks as compared to the current three to four months. In view of the potential for major cost savings, at little or no decrease in the teaching effectiveness of the lessons, it is important that educators, especially those in the U. S. Army TEC program, would be well-advised to consider this and other related research when planning, designing, purchasing and using audio-visual instructional materials and training aids.

SUMMARY

This study was designed to test the null hypothesis that there would be no significant difference in the achievement of subjects who are taught the same concepts using two sets of visuals which differ in detail, complexity, accuracy of scale and use of background. A 20-item comprehension test produced non-significant differences between the simple and complex artwork treatments within both the Army Reserve and UCF samples. Subjects in both target audiences achieved approximately the same comprehension level even though they perceived the complex art to be significantly more adequate to teach.

The major implication of this study is the possibility for dramatic savings in costs as well as time contributed to the development process of TEC lessons without a corresponding drop in teaching effectiveness. It was recommended that educators consider this and other related research when planning, designing, purchasing and using audio-visual instructional materials and training aids.

Fig. 1 Example of Complex Art as defined by the U.S. Army TEC Program.

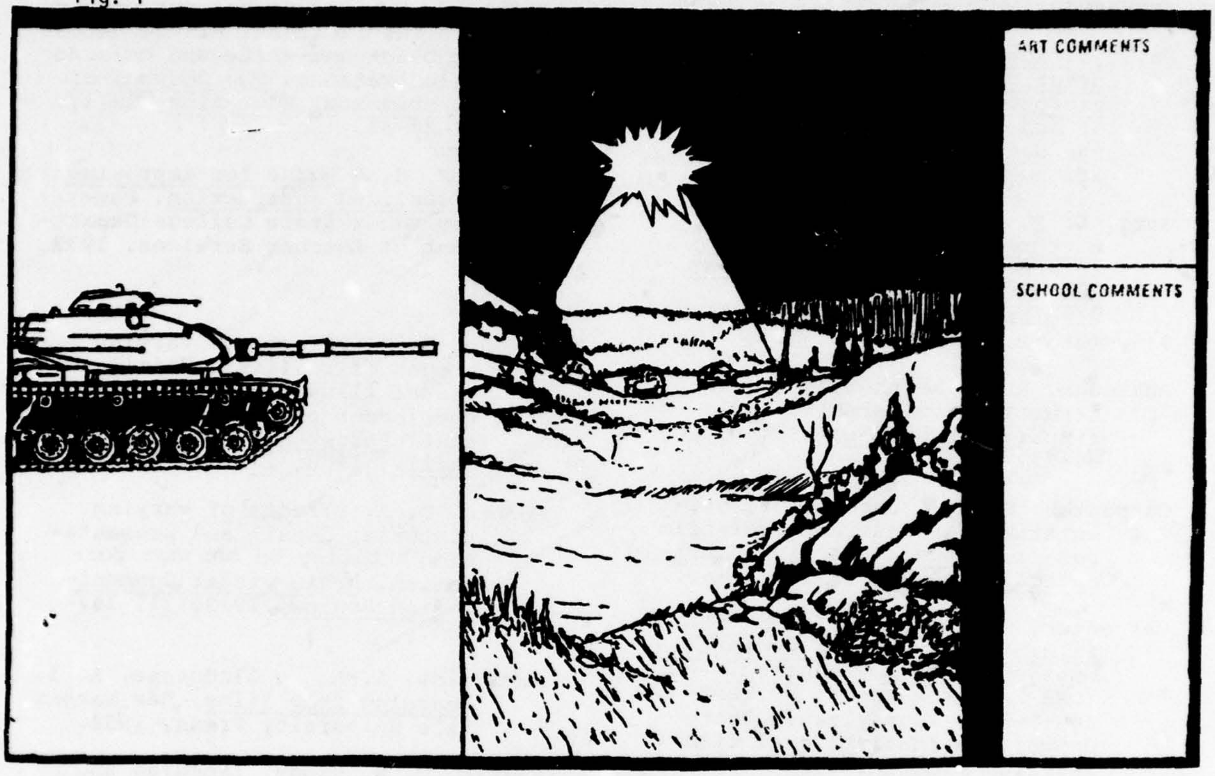
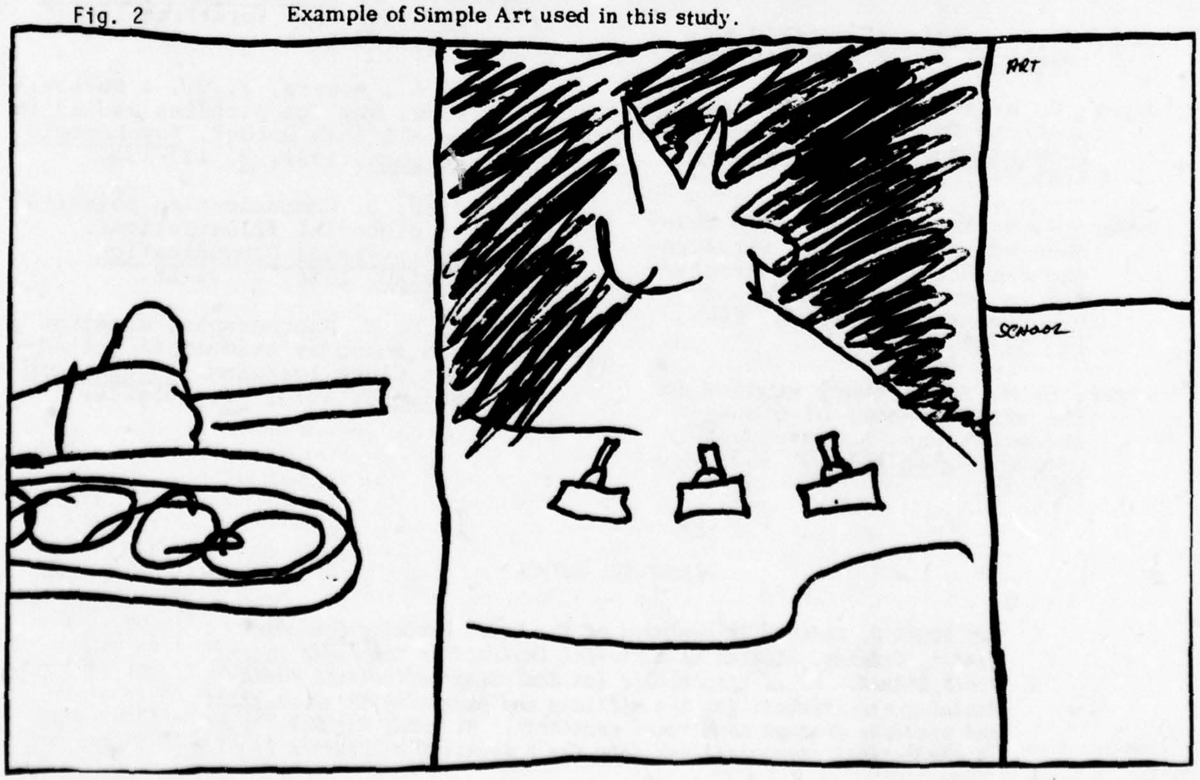


Fig. 2 Example of Simple Art used in this study.



REFERENCES

Ball, J. Research, principle, and practice in visual communication. Washington:Department of Audio-visual Instruction of the National Education Association, 1960.

Borg, W. R. The use of detail and background in visuals and its effect on learner achievement and attitude. Ft. Eustis, Virginia:Army Research Institute, July, 1977.

Bullough, R. V. Aesthetics and instructional materials. Audio-visual Instruction, 1974, 2, 69-71.

Carpenter, C. R. A theoretical orientation for instructional film research. Audio-visual Communication Review, 1953, 1, 38-52.

Carpenter, C. R. Evaluation of the film:Military police support in emergencies (Riot control). (ONR Research Report No. SDC-269-7-52). Pennsylvania State University:Instructional Film Research Program, 1954.

Dale, E. Audio-visual methods in teaching. New York:Holt, 1954.

Dwyer, F. M. Adapting visual illustrations for effective learning. Harvard Educational Review, 1967, 37, 250-263.

Dwyer, F. M. The relative effectiveness of varied visual illustrations in complementing programmed instruction. Journal of Experimental Education, 1967, 12, 34-41.

Dwyer, F. M. Exploratory studies in the effectiveness of visual illustrations. Audio-visual Communication Review, 1970, 6, 235-249.

Dwyer, F. M. Student perceptions of the instructional effectiveness of black-and-white and colored illustrations. The Journal of Experimental Education, 1971, 2, 28-33.

Dwyer, F. M. A guide for improving visualized instruction. Pennsylvania State College:Department of Learner Services, 1972.

Gorman, D. A. Effects of varying amount of realistic detail in visual illustrations designed to complement programmed instruction. Perceptual and Motor Skills, 1968, 27, 352-354.

Gorman, D. A. Effects of varying pictorial detail and presentation strategy on concept formation. Audio-visual Communication Review, 1973, 21, 337-350.

Lumsdaine, A. A., & Gladstone, A. I. Learning from films. New Haven: Yale University Press, 1958.

Morris, C. W. Signs, language and behavior. New York:Prentice-Hall, 1946.

Paivio, A., Rogers, T. V., & Smythe, P. C. Why are pictures easier to recall than words?. Psychonomic Science, 1968, 2, 137-138.

Spaulding, S. Communication potential of pictorial illustrations. Audio-visual Communication Review, 1956, 4, 31-46.

Wicker, F. W. Photographs, drawings and nouns as stimuli in paired-associate learning. Psychonomic Science, 1970, 18, 205-206.

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DESIGNER'S IMAGINATION AND EXISTING HARDWARE AND CREATIVE SOFTWARE PERFORMANCE-BASED MULTI-IMAGE INSTRUCTION

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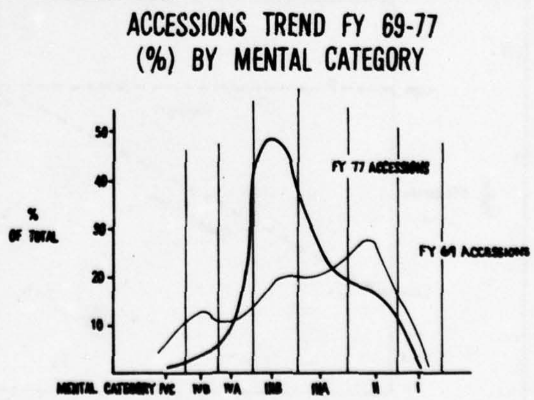
Today's Department of Defense has made great advances in developing and utilizing innovative training materials within the last 10 years. The Army, for instance, currently employs the Instructional Systems Development (ISD) model in the design of all training material. This model is unparalleled in defining and analyzing instruction in a very logical and coherent manner. However, the *model is only a tool. The development of* quality training packages is dependent upon the competence and imagination of instructional designers. This paper seeks to review and transcend the ISD model in suggesting methodological training innovations for cost-effective strategies to improve instructional packages.

Basically, the ISD model is an instrument which enables training developers to perform task analysis and undertake instructional development via a proceduralized logical progression. Each of the five phases of the model incorporates evaluation criteria which require the designer to answer questions, state objectives, analyze behaviors, make key decisions, etc. Idealistically, the ISD model is the most effective and efficient method to develop a training program. Inherent within the ISD model are provisions which enable the designer to determine adequate levels of design and production value for specific objectives as well as apportion resources necessary to provide maximum perspicuousness.

Design value can be operationally defined as the sum of all learning paradigms applied to a particular package. It can be viewed as an idealistic striving toward perfect attainment of instructional objectives. The effectiveness of the design of a learning package is measured by the behavior of the participants. It is construed as being successful if the elements of the lesson's behavioral objectives have been attained and demonstrated by the participants.

Production value refers to the technology of the method of delivery in an information presentation. The production value of a particular training program is often assessed in terms of aesthetics; e.g., special effects, graphics, casting, director's style, etc. Often the effect of an instructional program is determined by the amount of aesthetic distance that is felt by the audience. There are numerous variables which impinge upon this construct but generally the closer the aesthetic distance, the more favorably the program is received. We must concern ourselves with both the design value and the production value to successfully employ the ISD model in training for the modern Army.

Currently, Army developers are confronted with a serious and challenging training problem. The tactical equipment utilized in modern warfare is becoming increasingly complicated to both operate and maintain. This increased complexity of military equipment has caused the content of accompanying training packages to become commensurately more difficult. Along with this problem, the developer must deal with a target training population with demonstrated lower intelligence and reading scores than their counterparts of 10 years ago. (See Figure 1)

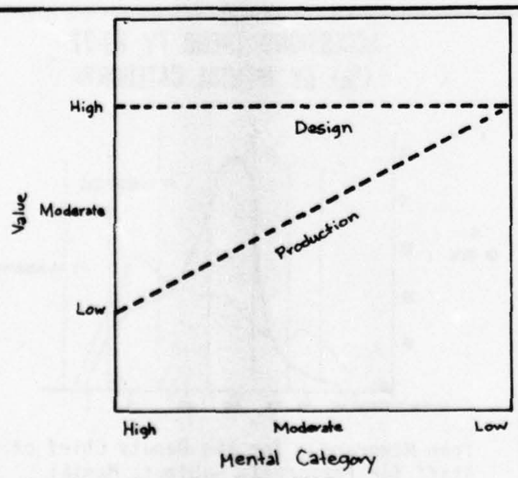


from Memorandum for the Deputy Chief of Staff for Personnel, Subject: Mental Quality of Army Accessions by Robert L. Nelson, Assistant Secretary of the Army, April 12, 1978.

Figure 1. Mental Quality of Army Accessions

It must be noted though that this problem is not specific to the military. Educational researchers have discovered this problem to be equally prominent in business and industry as well as the technical schools and universities. (Duke, 1978) This treatise does not purport to examine the underlying causes for this demise of test scores but rather seeks to offer suggestions as to how we, as trainers, may cope with this demanding situation.

There is no singular straightforward answer that can be offered as a solution to the above problem. Many variables must be analyzed and different learning situations must be considered. Initially,though, we as developers must adhere to the postulate that regardless of the training situation there cannot be any compromising upon the design aspect of training development. This design value requires a great degree of time and attention paid to it by the designer. Although production value varies with each training situation, the design value of the ISD model must remain consistantly high. Trainees with a great degree of intelligence and a high amount of motivation can effectively learn via any medium. "Slow" learners, on the other hand require training packages which are more elaborate and interesting. The production is thus inversely proportional to the analyzed intelligence and motivational level of the trainee. (See Figure 2)



from Dunathan, Arni T. "Allocating Resources Between Design and Production," Audiovisual Instruction (March, 1979): 17

Figure 2. Design and Production Values

Up to this point we have established and provided a rationale for the importance of the absolute value placed upon the design of instructional materials. We have also determined that there must be an increasing amount of attention given to the production value of training packages. We will now elaborate upon a suggestion which may be utilized by training developers to improve the production value of their training packages.

If we examine the interests of today's student population (individuals aged 6 to 25 years),we discover many interesting anomalies from previous generations. These people were raised with automobiles, jetliners, humans walking on the moon, and, of course, television. They are used to being constantly entertained and having things done instantly. Research shows that adults spend approximately 28 hours a week watching television; children average 25½ hours a week. Unfortunately if we look in the classrooms of today's public schools,we see many bored individuals. The reason for this is that many of our teachers in public education are unable to update their teaching methodologies to cope with today's student generation. They also cannot compete with the fast movement of the television. Army developers recognize that today's recruit is "turned off" by irrevelant material. They desire all the information deemed "necessary to know" for their occupation presented in the most interesting and expeditious mode possible. How can we, as training professionals, satisfy these criteria while also developing a cost-effective training system?

One simple answer to this problem is to apply the following simple equation:

Existing Training Material and Trainer's Imagination = Educational Innovation.

Today's Army classrooms currently utilize a wide array of modern training aids such as simulators, audio tape/slide shows, videotapes as well as traditional instructor-made visuals and chalkboards. Varying training objectives require the use of specialized training devices. A question we must ask is, "Are the existing training programs the most interesting, expeditious and cost-effective possible?" The answer is "no"! This paper suggests we combine all of our existing media into one presentation. This training innovation, which the Army is currently researching,is called multi-image instruction.

Perin's (1969) definition of the concept of multi-image is elaborated upon to provide an operational definition of multi-image instruction.

Multi-image instruction refers to a system whereby three images are projected simultaneously on three connected but separate screens. The center screen is a television monitor connected to a videotape viewer. The left and right screens are condensed movie screens upon which juxtaposed cue-pulsed slides are projected from the rear. These slides usually provide complementary information, but can also serve to create a panorama. The system is totally self-contained as shown. (See Figure 3)

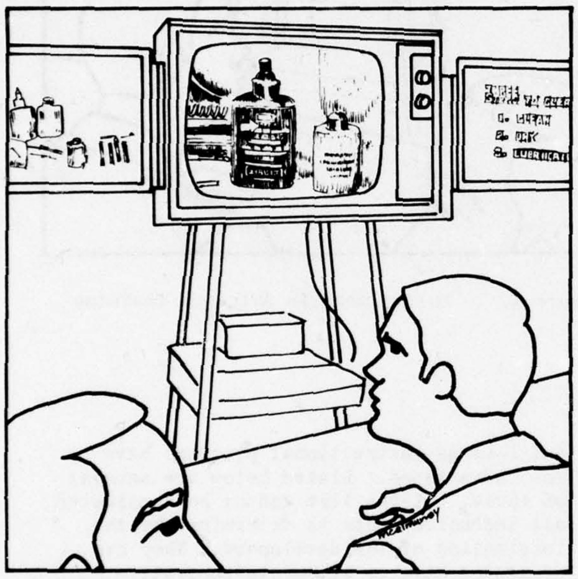


Figure 3. Multi-Image in Basic Training

The concept of multi-image presentations is not new--dating as far back as 1927. The advent of modern multi-image instruction occurred when James Finn and Robert Hall delivered a three-screen presentation in 1962. An evaluation report written on the program clearly demonstrated that,by utilizing larger screens or multiple screens with a battery of semiautomated equipment,it was possible to present many more concepts and much more complicated ideas to larger groups than had previously been thought possible.

Since that time,several studies have been undertaken in order to determine the effectiveness of multi-image presentations. Roshka (1958) and Allen and Cooney (1964) researched the effectiveness of multi-image instruction on the cognitive recall of children at the sixth-grade level and below. They found that the levels of recall are higher after multi-image presentations.

Reed (1970), using adult churchgoers as subjects,found that five screens were more effective than one in presenting religious information. Ingli (1972) demonstrated superior results with undergraduates using three screens to present information.

Brydon, working with trainees on blueprint writing at Lockheed Corporation Training Division,found that triple-image version of instruction was much more effective (.01) than a single-image version of instruction. Ausburn (1975) showed multiple imagery to be superior in aiding with visual location tasks. In addition,he found three screens to be extremely effective with haptic learners--an extremely significant finding for Army developers since the Army uses a great deal of "hands-on" training.

The results of research on multi-image are not overly persuasive about multi-image achieving superior results over conventional on screen or other training media. Research of the early 70's (Bollman, 1970; Atherton, 1971; Didcoct, 1972) shows no significant difference between the effects of single-image and multiple-image presentations. Conclusions of the research even state that multi-image presentations were interpreted as being so distracting that they were construed as detrimental to the learning process. Dyer (1975) offers an interesting rebuttal as an explanation of these conclusions. He maintains that the reasons for selecting the multi-image format range from its impact in emotional appeal to its effectiveness as an aid to instruction. Many developers neglect the design value of the presentation and rely solely upon the uniqueness of multi-image screening to evoke an audience reaction. He states:

> No behavioral objectives are identified, no follow-up evaluation is planned, and there are actually no results to be analyzed. The success of the program is measured in terms of supposed audience approval. Such a program may be developed to present a feeling to visually stimulate the viewer and to arouse the audience through sight and sound.

The Army combines this unique and important component of production value with a thorough and logical design analysis utilizing the ISD model. Therefore, the importance of design value remains constant (a high-priority level) while the attention paid to production value is increased.

Fort Gordon is currently experimenting with multi-image instruction in Basic Rifle Marksmanship (BRM). The objective of the training, which employs multi-image instruction,is to

enable the student to disassemble, lubricate and reassemble the M16A1 rifle. This instruction is conferred upon a recruit who has just recently (5 days) been inducted into the active Army. The novelty of being in the Army causes a great deal of apprehension in the student which acts as a deterrent to effective communication transfer. The BRM personnel wanted to eliminate this tension as well as retain a performance-based type of instruction. Therefore, in conjunction with the designers and media specialists, the multi-image format was implemented.

The concept utilized existing hardware (e.g., 35mm carrousel projectors, 3/4" video cassette players and television monitors) which can be found on all military installations. By combining the 35mm slide shows with the 3/4" videotape, a dramatic multi-image presentation evolved. Initially, the slides were changed manually, but the current multi-image presentation slides are automatically advanced via cue pulses on the secondary audio track of the videotape. Preliminary research results (Duke, 1979) show that recruits who view the multi-image presentation do as well on a performance test as troops enrolled in a traditional lecture class even though they complete the block of instruction in 65 to 75% of the time. This is due to the "hands-on" participation required by the multi-image program, the individualized instruction provided by BRM personnel and the standardization of the program.

The multi-image method of presenting training is not the best way to communicate all information. It is conditional in that its advantage over other media exists only where there is an increase in accessibility of relevant information. Nonetheless, multi-image can and does have application to numerous areas of training which require benefit from motion and/or animation. The avionic communication equipment MOS (35L), for example, can utilize multi-image training to create a pseudo three-dimensional effect as figure 4 illustrates.

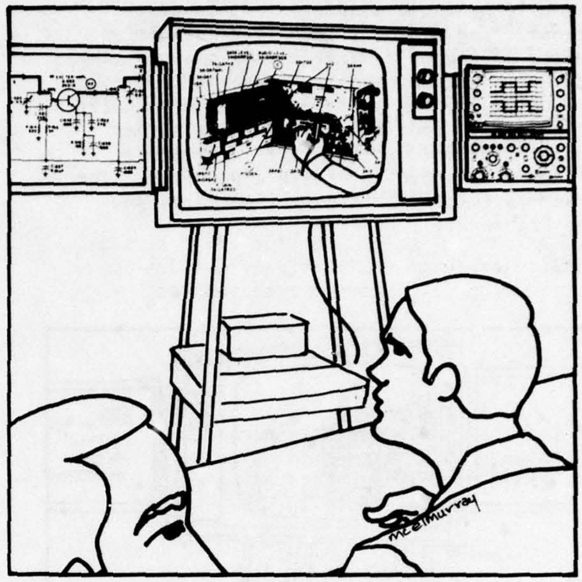


Figure 4. Multi-Image in Avionics Training

The left screen provides elementary hierarchical skills which are needed to accomplish the task. Here, basic electronic circuits, which appear in the repair task, are explained. This screen complements the center screen by informing the student what theoretically is happening. The center screen is a television monitor providing the motion. It shows the student: 1. the actual location of the components in question, 2. how to use a test probe to measure voltage, 3. how to properly set up the test equipment and, 4. safety precautions. The right screen illustrates how the measured voltage would appear on an oscilloscope.

Multi-image instructional programs have many advantages. Listed below are several of these, but the list cannot be considered all inclusive--this is determined by the imagination of the developers. They are presented here to stimulate innovative thinking for those who are considering the merits of using this format.

1. The position of behavioral objectives in the ISD hierarchy will determine the objectives-sequential position in the course instruction. The basic objectives; e.g., basic transistor theory, Ohm's law, etc. must be learned before higher objectives can be comprehended. Usually, this basic instruction is extremely boring due to its lack of application. The multi-image mode of presentation enables one to present or elaborate upon a low-level objective, when needed, on one screen, while constantly providing a reminder to the student of the concept's need and applicability on another screen. Thus, introductory tasks can be presented in conjunction with higher level tasks.

2. Careful attention to design value of the training program can cause the student to become actively involved in the program rather than remaining a passive viewer.

3. Utilization of three screens enables the designer to provide close-ups on one screen,

show the close up as it relates to the whole on another screen, and offer a visual explanation on a third screen.

4. A designer can use three screens to help the viewer identify commonalities, similarities, or contrasts among several visuals. It is easier to detect differences when the images can be viewed simultaneously.

5. An instructor who is proctoring a class with multi-image can provide individualized instruction with minimum interruption.

6. A multi-image program can be designed to include instructor evaluations before it continues with the lesson. If an instructor feels it is necessary, he can "still-frame" the program and personally elaborate on the material. This helps to provide better understanding of concepts presented prior to that specific point.

7. Multi-image programming, by its very nature, is a fast-moving media. A viewer is bombarded by three times as many images as television. This naturally forces him to be more attentive. Preliminary opinion polls distributed to recruits in M16A1 classes informed us that the students felt the program was moving so rapidly that they didn't have time to daydream. The fast pace caused them to concentrate three times as much as they would in a regular lecture. It must be noted, though, that the program must possess a logical and lucid progression as well as a juxtaposition of images.

8. Properly designed, a multi-image presentation is actually a three-dimensional type of simulation device. With the exception of direct simulation, this is the closest approximation to the actual performance of the task that is possible.

9. A secure (secret) program can be exported with no threat of its being intercepted and interpreted if a multi-image format is employed. One would be able to determine the objective of the presentation only if and when all three portions of the program are combined. These portions would be distributed separately and only when delivery of the one sent out previously is acknowledged by the receiver.

10. The technique of multi-image presentations is extremely cost-effective. Its basic components are a TV monitor, a videotape playback unit, two slide projectors with rear screen material, and a device that interprets the cue pulses on the videotape's secondary audio track to advance the slides. The material on the slides and videotape is determined by the designer.

As was mentioned earlier, the elaborateness of the production value of training is limited only by the imagination of the designer. Once he becomes receptive to new ideas, applications and technologies, his horizons are infinite.

For example, an interesting sidelight developed from our research on multi-image: We were concerned about field training in areas where conventional methods of instruction are not practical or inappropriate; e.g., repairing an antenna, soldering connections in a satellite terminal with extremely limited space, etc. To rectify training problems of this nature, we are developing a hand-held viewer which can be taken anywhere and upon which any type of training material can be easily illustrated. This compact audio and visual viewer can be used as a training aid in almost any conceivable training situation. Operating on ac current, or self-enclosed batteries, the hand-held viewer provides an individual an opportunity to watch either 16mm or 8mm filmstrips with audio accompaniment at his own pace. It can be used for initial training and/or reference as shown in figure 5.

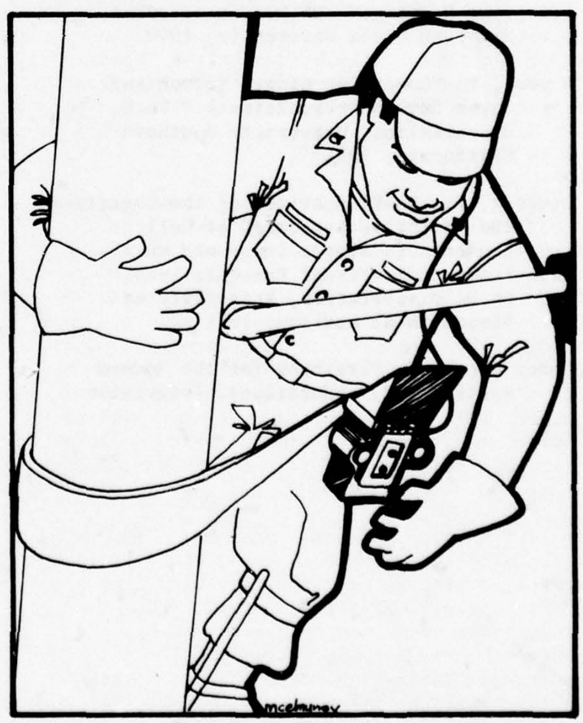


Figure 5. Hand-Held Viewer

In summary, this paper has sought to point out to educators that all the necessary ingredients of dynamic training programs are currently in existence somewhere in their immediate environment. By investing time

in a thorough design of instructional programs and relinquishing preconceived notions about traditional training programs, the instructional developer can creatively use his imagination to produce effective and innovative training material.

BIBLIOGRAPHY

Allen, William H. and Cooney, Stuart M. "Non-linearity in Filmic Presentations." AV Communication Review 12 (Summer 1964) 164-176

Atherton, Lawrence L. "A Comparison of Movie and Multi-Image Presentation Techniques on Affective and Cognitive Learning." Ph.D. dissertation, Michigan State University, 1971

Ausburn, Floyd Bonness "Multiple Versus Linear Imagery in the Presentation of a Comparative Visual Location Task to Visual and Haptic College Students." Ph.D. dissertation, University of Oklahoma, 1975.

Bollmann, Charles G. "The Effect of Large-Screen, Multi-Image Display on Evaluative Meaning." Ph.D. dissertation, Michigan State University, 1970

Brydon, W. "Comparing Single Screen and Three Screen Presentations." Ph.D. dissertation, University Southern California, 1971

Didcoct, Don H. "Comparison of the Cognitive and Affective Responses of College Students to Single-Image and Multi-Image Audio-Visual Presentations." Ph.D. dissertation, University of Wisconsin at Madison, 1972

Duke, Dennis S. "Training for the Modern Battlefield." Educational Television Program presented at National Security Industrial Association Conference, Fort Gordon, Georgia, October, 1978.

Duke, Dennis S. current research being undertaken at Fort Gordon, Georgia on the effect of multi-image instruction in the dissassembly, lubrication and reassembly of the M16A1 rifle.

Dyer, Palmer E. "Why Multi-Image?" Paper presented at the Association for Multi-Image Symposium II, AECT Convention, Dallas, Texas, April 1975.

Finstad, A. "Professional Sights Soar with Finn-Hall Spectacular," Audiovisual Instruction, 7 (June, 1962): 366-367

Ingli, Donald "Teaching a Basic AV Course by the Multi-Image Technique." Southern Illinois University, April 1972 ERIC No. ED 060 634

Lombard, E.S. "Multi-Channel, Multi-Image Teaching of Synthesis Skills in 11th Grade U.S. History." Ph.D. dissertation, University of Southern California 1969

Perrin, D. G. "The Use and Development of Simultaneous Projected Images in Educational Communication." Ph.D. dissertation, University Southern California, 1969

Reid, Robert O. "A Comparison of a Multi-Image and a Linear Film Format as Agents of Attitude Change." Ph.D. dissertation, Syracuse University, 1970

Roshka, A.V. "Conditions Facilitating Abstraction and Generalization." Voprosy Psikhologii 4 (No. 6, 1958): 89-96 (Reported by I.D. London, Psychological Abstracts 34 [1960] : 85)

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TRAINEE MONITORING, PERFORMANCE MEASURING, BRIEFING, AND DEBRIEFING

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INTRODUCTION

My purpose in writing this paper is to present in an organized way some of the methods that are being employed in today's state-of-the-art digital flight simulators to monitor trainee performance and provide simulator instructors with effective briefing and debriefing tools. It is not my purpose to suggest that the information presented herein represents the ultimate in design, or that it represents future methods that will be employed, since we in the simulation field know that much work is being done in this area and that much work remains to be done.

Rather, my intention is to present typical methods and system hardware that is being employed. You may draw your own conclusions as to the effectiveness of this typical system which will be described. In fact, it is my hope that you will find this paper an aid to drawing your own conclusions regarding this most important aspect of the simulation training problem.

REQUIREMENTS

There is a great deal of emphasis placed today by military using agencies on simulator manufacturers toward automating performance monitoring and instructor interaction during a training mission, and toward developing effective debriefing tools and automated unbiased performance monitoring systems. Government simulator specifications also emphasize the development of debriefing tools that may be used by both students and instructors at the conclusion of each training exercise. An artist's concept of a typical instructor's station, crew compartment, and computer peripherals that make up the trainee monitoring and scoring system is shown in Figure 1.

The importance of unbiased scoring of trainee performance cannot be overemphasized. The criteria for an effective system are:

1. Reliability

2. Fairness in the grading system

3. Ease of interpretation.

The performance monitoring system must allow for varying levels of trainee competency (one pilot may have 1000 hours of multiengine time, while another pilot may just be transitioning to multiengine). Manual grading may not give the desired results and could even give misleading information regarding the performance of one trainee over another.

With this overview in mind, I will now describe a typical system and some of the methods being employed.

PERFORMANCE MEASUREMENT PROGRAMS

Automatic Monitoring

Automatic monitoring generally consists of four unique areas:

1. Parameter and Variable Monitoring.

2. Mission Profile.

3. Procedure Monitoring.

4. Hardcopy Control.

The four areas may be operational together, separately, or in any combination. They are all created by the same process (problem formulation) and basically perform the same type of tasks in different areas. They are involved with measuring a student's performance to a predefined standard and then making this information available for hardcopy and subsequent printout to aid in student's evaluation.

The following is a brief description of the programs developed for the above unique areas:

1. Parameter and Variable Monitoring. This program determines the student's ability to maneuver the aircraft in a stable and safe condition. The student is graded against a set of predefined

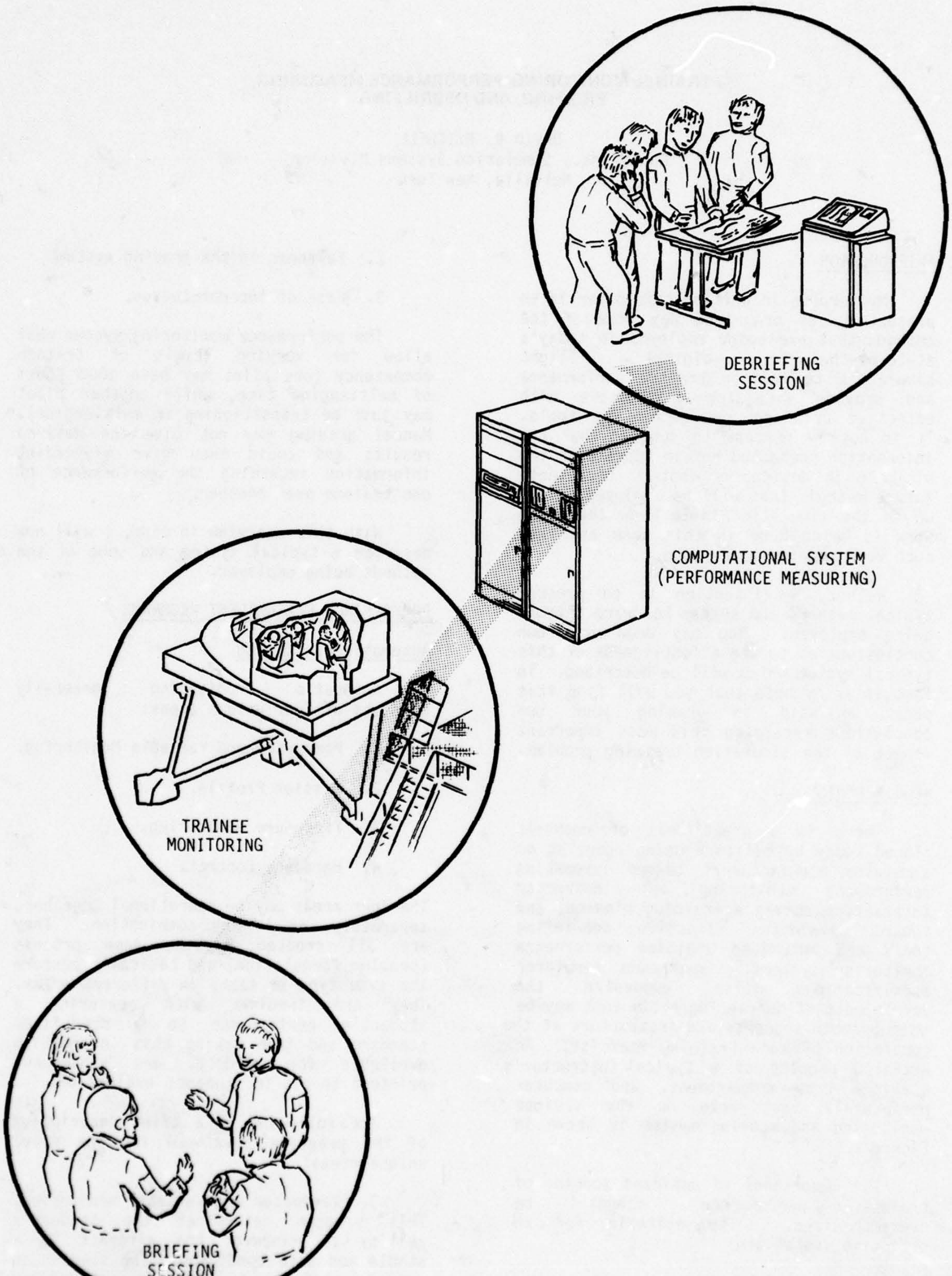

Figure 1. Typical Instructor's Station

variables as he performs various maneuvers and missions.

2. Mission Profile. This program defines an entire mission to free the instructor from performing time critical maneuvers, allowing him full time to instruct the student and monitor his actions during a predefined mission.

3. Procedure Monitoring. This program monitors the various procedures that the student must perform. These procedures, both normal and emergency, must be performed swiftly and efficiently and are monitored automatically by the computer for both speed and sequence. The student is automatically judged on the order in which he performs the task as well as the time required to complete a given procedure. The results are stored for later printout. A typical procedure as viewed by the instructor on his CRT is shown in Figure 2.

4. Hardcopy Control. This program allows the instructor to print out trainee errors as well as selected parameters.

Performance Measurement

Automated performance measurement programs are written to measure trainee performance on typical practice missions (programmed mission examinations) as well as on graded examinations (checkrides). During programmed missions, the performance measurement system has the capability to record, display, and retain for subsequent hardcopy printout parameters such as:

- Heading
- Barometric Altitude
- Indicated Airspace
- Angle of Attack
- Bank Angle
- Flap Position
- Vertical Velocity
- Rate of Turn,

plus a host of other aerodynamic parameters and navigational parameters. A flight/performance display such as that shown in Figure 3 aids the instructor in performing his own instantaneous evaluation and determining cockpit status.

Programmed measurements of trainee performance are provided for real-time displays for problem critique and stored for later analysis. Typical mission parameter profiles are developed and measurement routines are incorporated in

```
READY     (Time Lapse 00 Min. 00 Sec.)                    11/01/75
 NO2      Pre-Start Check

* 1.      Ground Locks - Removed and Stowed
  2.      Parking Brake - Set
  3.      Over head Circuit Breakers - In
  4.      Vapor Cycle Switch - Off
  5.      Cains - Off
  6.      Landing Gear Handle - Down
  7.      Condition Levers - GRD Stop
  8.      Side Circuit Breakers - In
  9.      Brake Selector Valve - Norm
*10.      Temp. Control Panel - Set
 11.      NAV Cool Switch - Off
 12.      Personnel A/C Switch - Off
 13.      RAM Air Selector - Closed
*14.      ICS - Set
*15.      Oxygen Reg/Bailout Bottle - 100 % Checked
 16.      Oxygen Supply Levers - On

ACTIVE    (Time Lapse 01 Min. 03 Sec.)                    11/01/75
 E02      Engine Failure on Takeoff - Aborted

✓1.       Power Levers - GRD Idle
 2.       Flaps - Up
*3.       Brakes - As required
*4.       If Arrestment is to be made
 5.       Arresting Hook - Down
*6.       Inform Control Tower
```

Figure 2. Typical Procedure

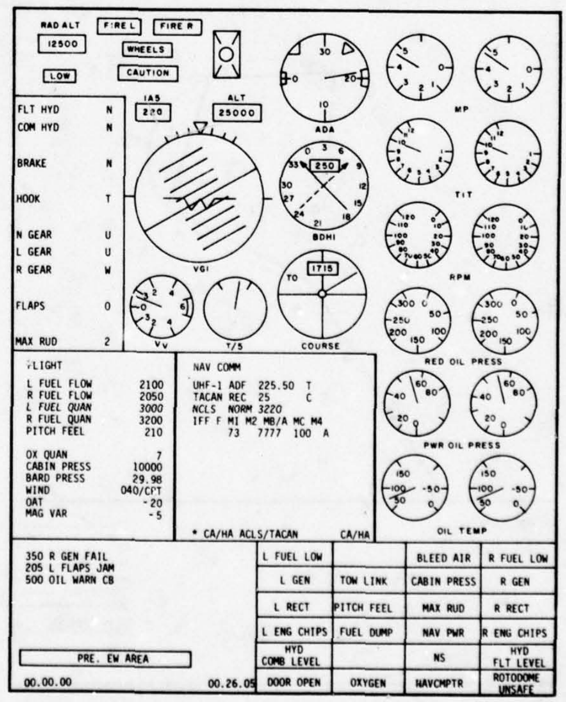

Figure 3. Flight/Performance Display

the simulation program to record deviations from the profiles. The performance measurement programs fall broadly into the following categories:

1. Computer-Aided Performance Measurement.

2. Performance Error Measurements.

A brief description of these programs follows:

1. Computer-Aided Performance Measurement. Programs are provided which compare trainee performance with preprogrammed ideal performance, automatically determining trainee errors. Provisions are also provided for the instructor to enter data for the trainee on performance parameters for which no "ideal" can be established (for example, communications expertise). The instructor is provided with CRT displays of approach areas and approach plates as shown in Figures 4 and 5.

2. Performance Error Measurements. During checkride mode of operation, and certain preprogrammed training exercises, errors in trainee performance are recorded wherever the performance on a particular parameter differs from that which has been designated as ideal for that performance.

This system also provides automatic data recording which relieves the instructor from the task of perceiving and recording circumstances or events where specific parameters and tolerances can be established. Error data is appropriately stored and outputted.

There is a level of difficulty in designing such a system, in that the system must be designed so that performance on one steady state leg does not affect performance measurement on subsequent legs; thus systems in which ideal performance is specified solely as functions of time intermission are not acceptable. The performance measuring preprocessing program must accept and process the following types of data:

a. Leg start or stop conditions in terms of applicable performance parameters. For example, "altitude greater than 600 feet and airspeed greater than 120 knots or heading between 100 and 120 degrees."

b. A list of parameters to be monitored by the RMS deviation technique (up to six per leg) and the desired value of each.

c. A malfunction number or other identification of a malfunction to be

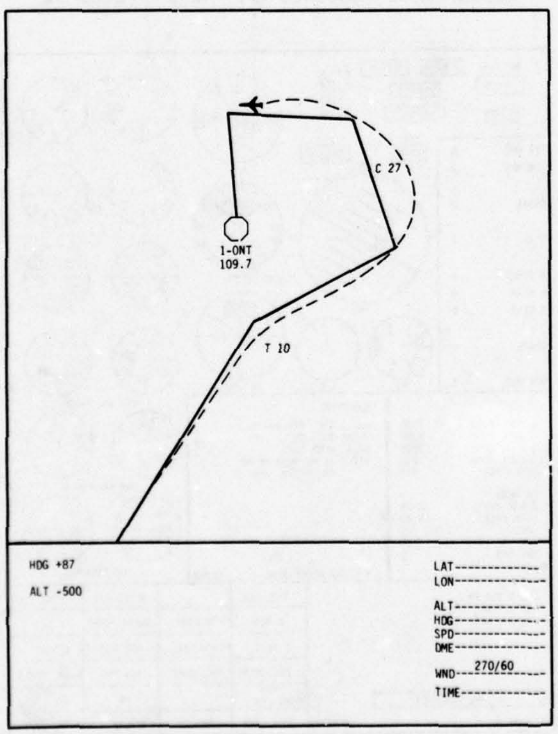

Figure 4. Approach Area

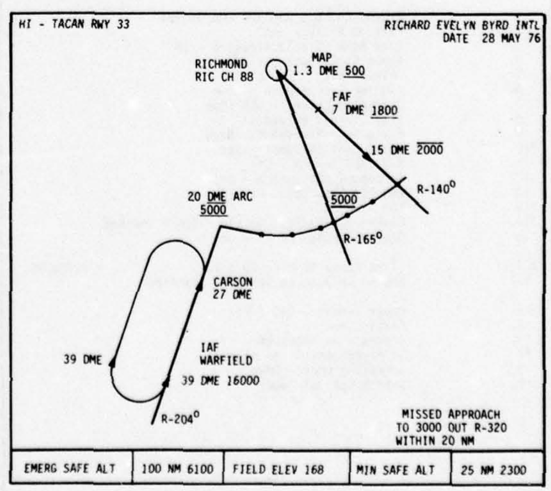

Figure 5. Approach Plate

automatically inserted or deleted when the leg begins, or when conditions, similar to the start/stop condition required in a. above, are satisfied.

d. A set of conditions in terms of applicable performance parameters which would result in a critical or procedure error being recorded. These shall be similar in form to the start/stop conditions required in a. above.

e. Provisions for accepting instructor inputs concerning transmission errors.

Performance Recording

Now that an effective performance measurement program has been designed, it is necessary to provide recorded outputs for evaluation and grading. It is also required that an easily interpreted record be provided that can be used by both students and instructors.

Hardcopy printout as shown in Figure 6 is an effective way to accomplish this. As may be seen, the hardcopy consists of the checkride title and numbers, a summary of procedures called and missed steps, RMS and Z score data for each segment and the total mission, PE, CE, and TE error listings, an automatically scaled image of entire mission with ground track error symbols, and up to 10 snapshots of mission displays.

CONCLUSION

The foregoing paragraphs have outlined a typical automated training and scoring system by showing the man-machine interface in a training environment. I have tried to present an overview of the computer programming requirements for a system that is fast moving to the forefront of simulation technology as the demand for valid, unbiased trainee scoring systems increases.

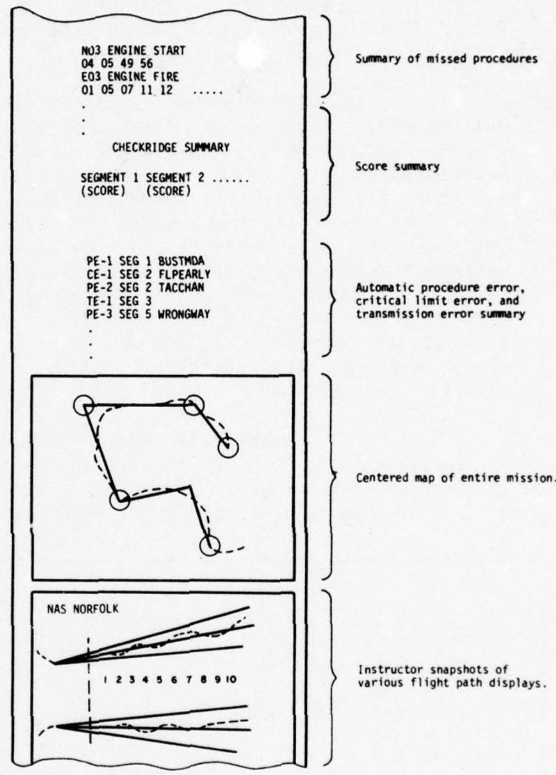

Figure 6. Hardcopy Printout

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INTEGRATION OF ELECTRONIC WARFARE SIMULATION INTO THE F-16 WEAPONS SYSTEM TRAINER

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INTRODUCTION

The F-16 Simulator Program consists of the purchase of a set of Weapons System Trainers (WST) for the United States Air Force, plus expanded Operational Flight Trainers (OFT) for the Unites States Air Force, the Royal Norwegian Air Force, the Royal Danish Air Force, the Royal Netherlands Air Force, and the Belgian Air Force as well as for Foreign Military Sales.

An F-16 WST will consist of the systems illustrated in Figure 1. Each of the systems, the basic OFT (hereinafter designated OFT), the Electronic Warfare Trainer Device (EWTD), the Digital Radar Landmass Simulation (DRLMS), and the Fighter/Attack Simulator Visual System (F/ASVS), is known as a building block.

An expanded OFT will consist of an OFT, and either a DRLMS, and EWTD or both. It does not include a F/ASVS or interconnection of OFT cockpits.

Each building block will be purchased on separate contracts. The Simulator System Program Office developed this concept to take maximum advantage of technologies in each area of simulation without being constrained to a single contractor's approach.

This paper will discuss the system engineering aspects of the integration process and their application to the preparation of the Request for Proposal (RFP) for the F-16 EWTD. It will begin with an overview of each building block and then it will discuss four basic integration principles. Next it will briefly overview the Electronic Warfare (EW) simulation problem. Finally, it will discuss the application of the basic integration principles to the EWTD procurement and how this application resulted in the derivation of another principle which was also applied to the EWTD and will become central to integration of other building blocks.

BUILDING BLOCKS

The basic element of the WST is the OFT. The contract for the device was awarded to the Singer Company, Link Division, in November of 1977. The first device is scheduled to be delivered to USAF in May 1980. The OFT simulates all F-16 aerodynamics, all aircraft systems, and all on-board avionics systems except those dealing with Electronic Warfare. The full capability of the F-16 radar is simulated,although the air-to-ground simulation uses an artificial data base rather than a "real world" data base. The OFT simulates radio navigation facilities, jammers for the radar, as well as aircraft and missiles encoun- by the F-16. Some of the OFTs include a night visual system. Finally,the OFT provides an extensive instructional system to aid in training and a set of Norsk Data NORD 10/5 and NORD 50 computers to control the exercise.

The EWTD will operate with the OFT. The device will simulate the F-16 EW equipment. It will also provide an extensive EW environment to simulate various radar systems which the F-16 may encounter on its mission. Source selection for this device began in June 1979.

The DRLMS will supplement the existing air-to-ground radar simulation for the one OFT of a WST with a "real world" data base provided by the Defense Mapping Agency. The Air Force plans to issue an RFP for DRLMS in late 1979.

The F/ASVS will provide a wide field of view visual scene for air-to-air and air-to-ground training. The system will also use a "real world" data base. Two prototype F/ASVS are currently being developed for the A-10 WST by General Electronic Company and the Singer Company, Link Division, under contracts awarded in September, 1978. It is planned that a production F/ASVS will be integrated with the remainder of the F-16 system about 1984. At this time,the two OFTs will be connected to provide interactive train-

ing. The capability for independent training in each OFT will be retained.

In order to satisfy Tactical Air Command training requirements the development of the OFT proceeded before all the requirements for other building blocks were completely defined.

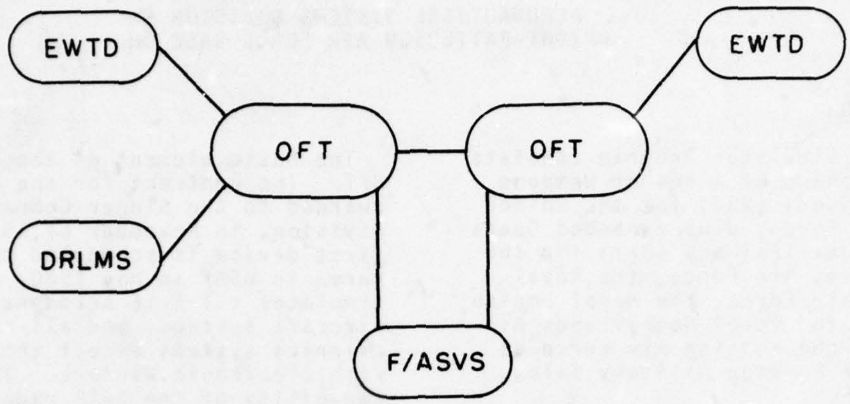

FIGURE 1. THE F-16 WST

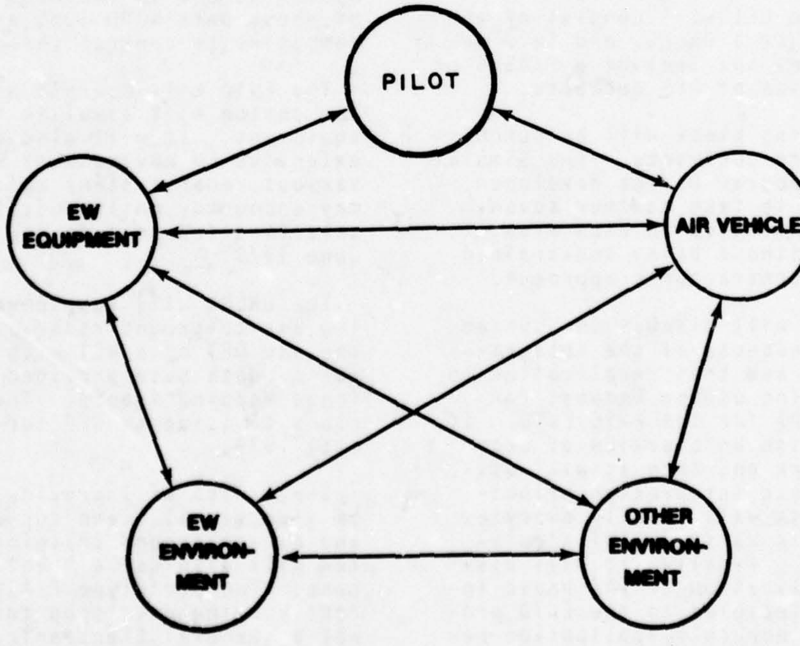

FIGURE 2. THE EW PROBLEM

The prototype F/ASVS requirements were primarily addressed to the A-10 WST. So, at the time requirements for the EWTD and DRLMS were being developed, it was realized that extensive system engineering was necessary if the Air Force was to successfully integrate the building blocks to provide the F-16 WST and expanded OFTs required.

BASIC INTEGRATION PRINCIPLES

Given the basic building blocks definitions previously discussed, the Simulator System Program Office investigated the problem and established several basic principles. These were:

a. Since all expanded OFTs and WSTs contain an OFT, the OFT must be recognized as the heart of the system. Other systems should take advantage of capabilities provided by the OFT to the maximum extent possible.

b. There should be maximum commonality in hardware and software among the building blocks. Since the OFT was already on contract, other building blocks should conform to the OFT.

c. In operating and maintaining the WST, the building blocks should be transparent to the user; i.e. operating and maintenance techniques should be identical for the entire WST.

d. The building blocks should be modular; i.e. each building block could be added to the OFT without dependence upon the presence of others.

THE ELECTRONIC WARFARE SIMULATION PROBLEM

Before discussing the application of these basic principles to the EWTD integration, let us review the EW simulation problem. The EW problem to be simulated in the WST or expanded OFT may be envisioned as a set of dynamically related subsystems and interface as shown in Figure 2. Figure 2 may be considered as applying to both the real world and simulators since there is almost a one to one correspondence between subsystems and interfaces. The EW equipment and EW environment are the subsystems of primary interest.

On the F-16 aircraft the EW equipment consists of the AN/ALR-69 Radar Warning Receiver, the AN/ALQ-119 or AN/ALQ-131 pods and the AN/ALE-40 Chaff and Flare Dispenser. Each of these equipments has one or more control and display panels in the F-16 cockpit.

The ALR-69 analyzes signals produced by radar systems in the EW environment using a receiver and a digital processor whose program determines the most dangerous EW systems and provides warning symbols on a small Cathode-Ray Tube. It also provides audio alarms to the pilot. The pods provide jamming to counter the EW environment and the ALE-40 allows release of chaff and flares to perform the same function. The EWTD tries to fully duplicate the performance of the "real world" F-16 EW equipment. Certain EW equipment interfaces with lights and switches provided by the OFT.

The real world EW environment is a collection of friendly and enemy electronic and weapon systems. The WST EW environment attempts to duplicate the real world. The WST EW environment consists of a set of JARMS*. JARM is an acronym which stands for jammer, artillery, radar or missile system. It is the generic term for a simulation of any friendly and hostile systems external to the simulated F-16 which can search for the simulated F-16, track it, launch simulated weapons against it, jam its radar or communications, etc. In order to completely simulate the EW systems in the environment,the JARM consists of various elements as illustrated in Figure 3. The emitter provides simulation of the electromagnetic characteristics of the real world system represented by a JARM; it forms the EW equipment/EW environment interface. For real world systems with vehicle,the JARM platform provides the simulated dynamics as well as the proper representation on the visual and sensor systems. A site provides the same function for real world systems which are fixed. JARM tactics provide the basic rules of JARM operation and, with the JARM Countermeasures Evaluator(JARMCE) and JARM Weapons, is involved in war gaming simulation. JARM weapons are also presented on the visual system.

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* The term JARM and the remaining terminology in Figure 3 has recently been developed by the Engineering Division of the Simulator System Program Office, Aeronautical Systems Division to obtain more precise meanings for terms used in EW specifications.

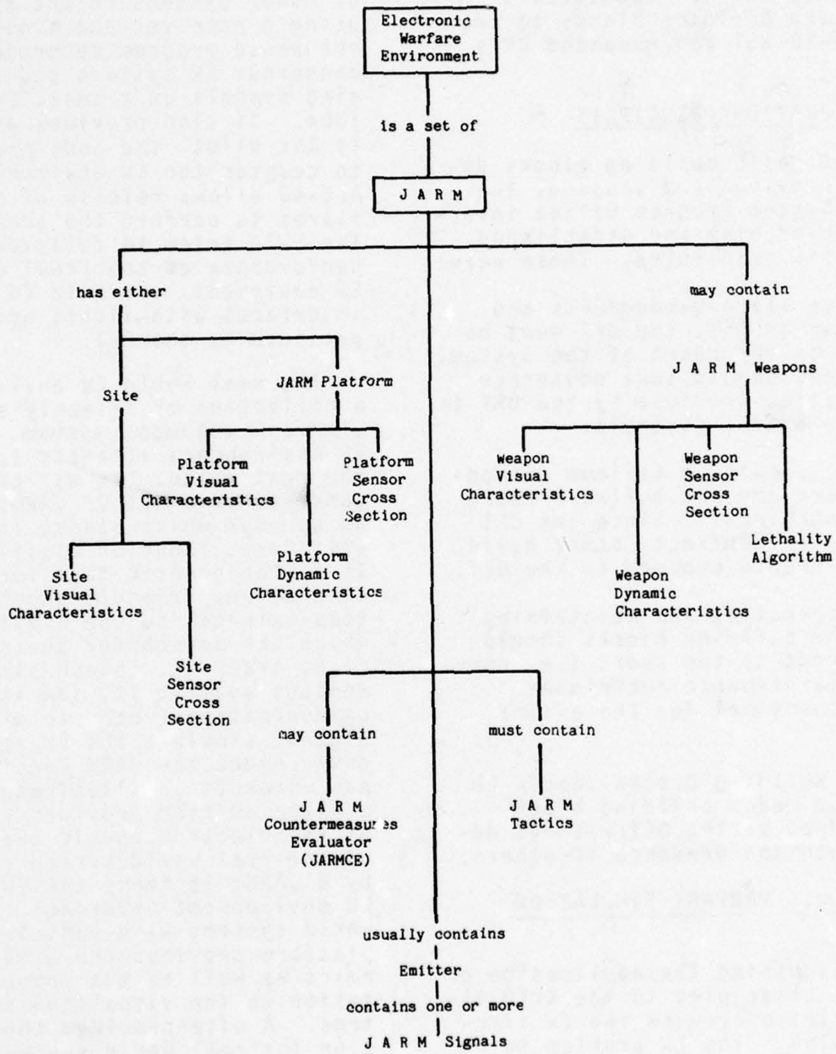

FIGURE 3. JARM ELEMENTS

REQUIREMENT	OFT	EWTD/DRLMS/F/ASVS			
1. ALR-69 Simulation	Interface	Yes	No	No	Interface with OFT Electronic System.
2. Chaff and Flare	Partial	Yes	No	No	Release switch in OFT: interface with OFT electrical system.
3. Pods	Partial	Yes	No	No	Aerodynamics simulated in OFT; Interfaces with OFT electrical system.
4. JARMS					
4a. Emitters	Some	Yes	No	No	Jammer emitters in OFT
4b. JARM Tactics	No	Yes	No	No	
4c. JARMCE	No	Yes	No	No	
4d. Sites	No	No	Yes	Yes	Sensor cross section in above DRLMS; Visual Characteristics in F/ASVS.
4e. JARM Platform					
4e1. Dynamic Characteristic	Yes	No	No	No	
4e2. Platform Sensor Cross Section	Yes	No	Inter face	No	Sensor cross section in OFT: also appear on DRLMS.
4e3. Platform Visual Characteristics	Limited	No	No	Yes	
4f. JARM Weapons					
4f1. Weapon Visual Characteristics	Limited	No	No	Yes	On OFT night visual
4f2. Weapon Dynamic Characterists	Yes	No	No	No	OFT modified to include simulated Anti-Aircraft Artillery and Additional Missile Trajectories.
5. JARM Occulting	Interface	Inter face	Yes	Yes	Occulting provided by either DRLMS of F/ASVS.

TABLE 1. ALLOCATION OF EW REQUIREMENTS

THE INTEGRATION PROCESS

The EWTD integration process began with an examination of requirements for the total WST. Once a requirement was identified,the first step was to apply the first basic principle and ask, "Is the required capability provided with the OFT?" If the capability was provided, the decision was made to use the OFT capability even though modification might be required. If the capability was not provided,the question was then asked if the requirement should be provided by the EWTD or by the other building blocks. Most answers were obtained using a high-level definition of the functions of the EWTD, DRLMS and F/ASVS. Table 1 illustrates the results of this process for various requirements related to EW simulation.

After the requirements were allocated to the various building blocks, the basic requirements for the EWTD could be written but additional work was still needed. This consisted of application of the remaining basic integration principles to the EWTD. It also resulted in the derivation of a new principle.

COMMONALITY

The next step was to apply the commonality of hardware and software principle. This began with an investigation of the EWTD computer system. The use of spare core and time within the OFT computation system was examined. We estimated that the EWTD would require about 59,000 words of memory and 790 milliseconds of processing time per frame using one or more of the OFT computer processors. This was available within the spare capability of the OFT; however, after much discussion this approach was rejected. The technical reasons for this decision included:

a. Such an approach would require the EWTD contractor to modify the OFT software, would require the OFT contractor to program the EWTD, or would require a very complex interface between the contractors.

b. OFT spare time and core requirements, needed to accommodate future changes in aircraft configuration and other building blocks, would be lost.

After deciding that the EWTD should have its own computer system we then decided that the EWTD computer should be identical to one of the OFT computers since this provided maximum commonality with the OFT and resulted in simplification of logistic and maintenance procedures as well as reduction of life-cycle costs. It also provided opportunities for the use of common software and sharing of peripherals. Finally it allowed us to meet F-16 program requirements to purchase equipment in participating European countries.

We then decided to take advantage of the opportunities for common software by requiring that the EWTD contractor use OFT programming support software for such functions as the symbol dictionary and encouraging the EWTD contractor to use other OFT software where practical and where such software was available. This was possible because we had obtained unlimited rights to the use of all OFT software.

Since the EWTD used a computer system common to the OFT,we had the opportunity to share peripheral devices between the OFT and EWTD computers. We required the EWTD to do this.

The most interesting application of commonality dealt with the use of OFT Signal Conversion Equipment (SCE). The SCE is used to input data from the OFT cockpit and instructor stations to the OFT computer system,and to output data from the OFT computer system to the OFT cockpit and instructor stations. The SCE could handle two kinds of variables, discrete and analog. Discrete SCE is used to input switch positions from the cockpit and the instructor station to the computer and to output light status. Analog SCE is used to input setting of continuous controls and to output drive signals for various instruments. Other more complicated interfaces are not handled with SCE. Since the EWTD uses many discrete switches and has many lights, use of discrete SCE was possible. Analog SCE had little application to the EWTD. Audio and video outputs associated with the RWR could not be handled by SCE.

We investigated possibility of requiring the EWTD to use the OFT SCE. The two alternative approaches are illustrated in Figure 4. A trade-off study was conducted. The results are illustrated in Table 2. Cost was also considered but it was not a

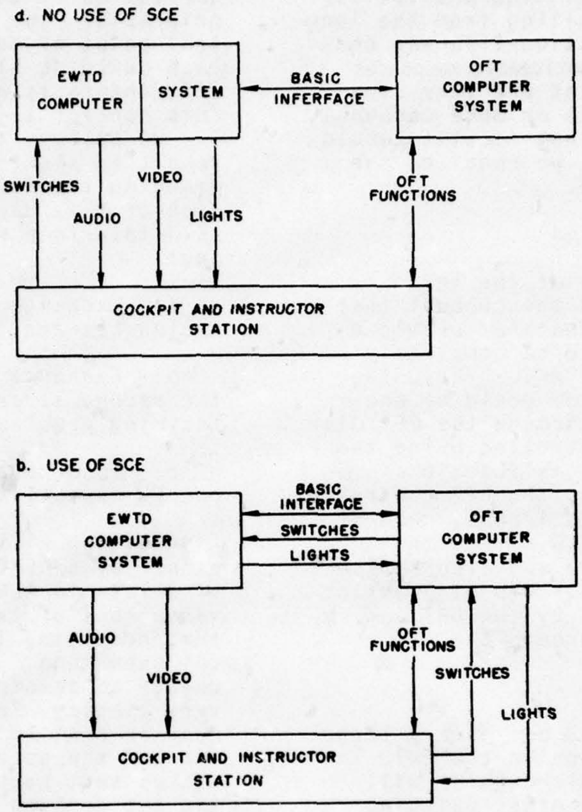

FIGURE 4. ALTERNATE ON SCE

PRO	CON
1. OFT diagnostics check input/out put for switches and lights. All discrete input/output handled identically.	1. Contractor must work more closely together.
2. Since OFT handles all switches and lights it can provide most record and replay functions by driving the EWTD.	2. Possibility of time delays in information transfer.

TABLE 2. SCE TRADEOFFS

major factor since the EWTD has only a few simple panels. The possibility of time delays resulting from the longer path for information flow was considered but since noticeable responses of the EWTD equipment are very slow (on the order of one or more seconds), it did not appear that fidelity would be degraded. Thus, we required the EWTD to use OFT SCE.

Transparent Operation

The prime example of the third basic principle was the concept that all instructional features provided with the EWTD should be completely integrated with the OFT. Thus, the EWTD training problem could be completely monitored through the OFT display system and controlled using the OFT keyboard. EWTD malfunctions would be inserted by the OFT controls. OFT controls such as freeze, record and replay would also affect the EWTD. The principle was also applied to diagnostics; i.e. EWTD diagnostics would be controlled by the OFT and results reported through the OFT.

Modularity

This principle did not have a large degree of application to the EWTD integration process,although it will be more important when other building blocks will be added. In general, the interfaces of the EWTD are largely with the OFT as can be determined from an examination of Table 1. Interfaces with the DRLMS and F/ASVS are merely to accomplish occulting and correlation of indications. If either of these building blocks were not present,the interface could be largely an "open circuit." We also wanted to design the EWTD/OFT interface so that modification will not be necessary as other building blocks are added. In thinking about this principle, we derived a final principle of integration.

The Derived Principle

In examining the EWTD integration problem, we realized that almost all information exchanged was between the EWTD and OFT. After further thought, we realized that this also applied to DRLMS and F/ASVS. It was also clear that in all cases, high rates of information exchange were necessary only between the OFT and DRLMS and the OFT and F/ASVS. Thus, all information exchange could be routed through the OFT. This led to the derivation of the final integration principle. The OFT should be a central point of communication; that is, each building block, other than the OFT, interacts only with the OFT. This concept is illustrated in Figure 1. We believe that the principle will result in significant advantages in managing the interfaces. Application of this derived principle to the EWTD interface resulted in the following:

a. Exchange of occulting information between the OFT and EWTD.

b. Exchange of information on the second aircraft in integrated WST training problems.

c. Incorporation of the two on one EW capability into JARM Tactics.

Occulting will be accomplished either by F/ASVS or DRLMS. Because of delays in ALR-69 processing and variations of tactics in the EW system, occulting is not a time critical phenomena. The information exchange to accomplish occulting is very simple. Position of each JARM must be sent to the occulting system and the occulted/not occulted status sent back to the EWTD. Applying the derived principle,we incorporated an OFT/EWTD interface to accommodate occulting. It is planned that the OFT will interface with DRLMS or F/ASVS to accomplish occulting. When the system which performs occulting is added, the EWTD will request a check from the OFT. The OFT will route the request to DRLMS or F/ASVS. The status received by the OFT will be sent back to the EWTD.

Information exchange on the second simulated aircraft and the status of its EW equipment is necessary for integrated training in an interactive mode in both cockpits of the WST. The simulated EW environment must respond to both aircraft simultaneously. Since the OFTs will not be integrated until F/ASVS is available for the F-16, we decided that the EW environments should be independent with information exchange to accomplish the concepts discussed herein. The information exchange between OFT and EWTD to accomplish such an interface was specified in the EWTD RFP. Figure 5 illustrates the concept for interactive as well

as independent training as it would be applied to a typical JARM in the EW environment. In interactive training the logic would be accomplished simultaneously for both OFT cockpits within the WST, but the results would appear to act like a single EW system.

CONCLUSION

After applying the integration principles, the tasks necessary to accomplish them for the OFT/EWTD interface were defined in detail. The tasks were then divided into two areas, changes to the OFT and features in the EWTD. The OFT contractor was requested to prepare an Engineering Change Proposal to accomplish all changes to the OFT. The EWTD RFP required the EWTD contractor to accomplish those tasks on his side of the interface.

We believe that the principles discussed in this paper apply not only to the OFT/EWTD interface, but also apply to the integration of other building blocks with the OFT to form a WST or expanded OFT. We plan to apply these principles first to the EWTD integration, then to DRLMS integration and then finally to F/ASVS integration. This step-by-step procedure will allow us to incorporate lessons as they are learned. However, we do not believe that either the four basic integration principles or the derived integration principle will need to be modified.

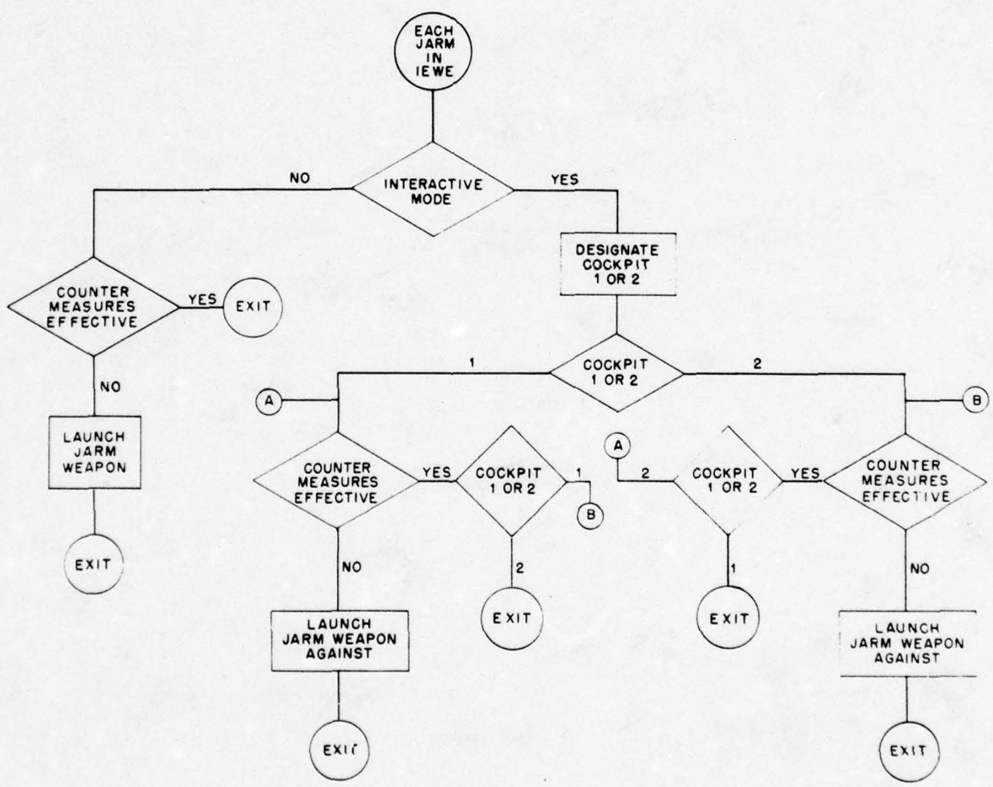

FIGURE 5. INTERACTIVE JARM TACTICS

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A MECHANISM FOR COMMUNICATING SIMULATOR INSTRUCTIONAL FEATURE REQUIREMENTS

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BACKGROUND

The history of flight simulation has been characterized by almost constant advances in the capabilities and complexity of flight training devices. Most of these advances have involved increased fidelity of simulation. That is, simulator design has emphasized physical correspondence between the device and the aircraft simulated and between the simulated and aircraft (real) environments. As a result, flight simulators increasingly look, feel, sound and perform like aircraft.

The emphasis upon fidelity in simulator design has resulted in devices that are costly to procure and operate. In spite of such costs, however, fidelity in flight simulators is widely acclaimed as useful and, in many cases, even essential to effective training. Because of the cost of high fidelity devices, the development of simulator designs that permit more efficient training is a necessary goal.

A simulator designed to permit efficient training is one whose instructional and other features permit instructional activities to be conducted with a relative minimum of time and effort. Several recent efforts to develop more efficient simulators have sought to achieve greater efficiency by eliminating the instructor from portions of the instructional process through development of instructional features that permit automatic training and performance measurement (e.g., Brown, Waag and Eddowes, 1975, Semple, Vreuls, Cotton, Durfee, Hooks, and Butler, 1979). Others have concentrated on developing new measures of performance (Walsh, Burgin, and Fogel, 1979) or on manipulation of the task cues present during simulator training (Hughes, Paulsen, and Brooks, 1978). A few studies have examined the role of the instructor in non-automatic simulator training and the manner in which the simulator's instructional features facilitate or hinder that role. These latter studies have concentrated upon simulator instructor/operator stations (IOS)--the locus of control of most instructional features--and the extent to which IOS design impacts instructional efficiency.

In one study of IOS designs, Charles, Willard and Healy (1976) observed that some of the newer flight simulators are less efficiently designed than older ones. They noted that earlier designs, while not based on systematically derived training requirements, were sufficiently constrained by display and control technology to result in a meaningful and relatively efficient IOS arrangement for the instructor.

SUMMARY

Although current generation simulators incorporate a number of presumably useful instructional features, several researchers have noted that the designs of these features often make them awkward and inefficient to use. It appears that these features were designed without sufficient information about how they were intended to be used during training. An examination of the simulator design and development process indicates an absence of a convenient mechanism for providing this information to simulator designers. The project described here was undertaken to develop such a mechanism.

Descriptions were developed of simulator instructional activities associated with instructional features found on current generation flight simulators. The purpose of these descriptions, or Simulator Instructional Feature Design Guides, was to facilitate communications between simulator users and designers by documenting information about the intended use of simulator instructional features. Guides of this type provide the simulator designer with the kinds of information required to evaluate the utility and efficiency of instructional feature design alternatives. By using such guides the designer may effectively simulate the training process as a part of his design efforts.

The content of the guides is based on observation of simulator instructional activities and reviews of training requirements and practices associated with a fighter/attack type aircraft. The 12 design guides developed during the project were reviewed by personnel involved in all phases of the design, development, and training uses of flight simulators. It was their consensus that the guides would be useful in future simulator projects as a mechanism for clarifying simulator design requirements, communicating between training and design personnel, highlighting design shortfalls, and clarifying simulator testing requirements. In addition, the guides have been used, in modified form, to clarify requirements for the design of a simulator for a tank and to facilitate communication of design information between that device's eventual user and the device developer. The guides are currently being used in conjunction with the development of simulators for a utility-type jet airplane and a helicopter. Experience gained with the guides on these projects will provide further information concerning their utility during the simulator design process.

Two of the design guides developed during the project are presented.

Today, by contrast, advanced control and display technology has been exploited seemingly to cover all possible contingencies rather than to permit conduct of necessary instructional activities in an efficient manner. Charles, et al, concluded that "Efficient training console design can be accomplished, but only if display and control designs are based on information and action requirements . . .. Thus, the role of the [simulator instructor/operator] must be defined in detail and the operational concept developed" (pg 76).

Inefficiencies in IOS design were also noted by Isley and Miller (1976) during an examination of both military and commercial flight simulators. They reported that modern simulators incorporate a large number of presumably useful instructional features, but that many of these features were not being used in the conduct of simulator training. Two reasons were given to account for this situation: (1) the designs of simulator instructional features were inefficient, and use of the features often proved time consuming and awkward; and (2) the features themselves were in some cases inappropriate to the training being conducted in the devices. Isley and Miller noted that the designs of the simulators they examined appeared to have been developed in the absence of information about an operational concept of the training to be provided or about the intended role of the instructor. That is, the kind of information needed for design of an efficient IOS (as identified by Charles, et al) probably was not available to the designers of the simulators Isley and Miller examined.

Review of the process in which simulators are designed, especially U.S. military flight simulators, confirms the general absence of such information. Simulator specifications and other design and procurement documents seldom address operational training concepts or instructor roles. By contrast, information about the aircraft to be simulated and its operational environment is addressed in these documents and serves as guides for simulator design. Usually, training objectives documents provide further design guidance to assure that the required skills and knowledges can be developed in the planned simulator. But, there is no guide to aid the designer in assuring that the operations necessary for efficient training in the planned simulator can be conducted. While instructional features may be specified in the design documents, the manner in which they are expected to be employed by the users of the simulator simply is not made known to the device designer.

Isley and Miller did note, however, that there are simulators in which some of the instructional features were efficiently designed in spite of the absence of information about the manner of their intended use. Such features were used during training with these simulators and were judged to increase the efficiency of training in the devices. After further study by the present authors of several of the simulators examined by Isley and Miller, it was concluded that the relatively efficient design of instructional features probably was achieved in part by "simulating" representative training activities, using a mock-up of the simulator's IOS and trainee station, and modifying the mock-up as required to permit training activities to be conducted efficiently. Unfortunately, those efforts tended to be unsystematic and incomplete because of the limited time during which the mock-up was available to personnel familiar with simulator usage. Further, these efforts usually occurred only after most of the design decisions were made, and only questions related to control-display arrangements remained to be answered.

Thus, it would appear that information about the intended use to be made of a simulator's instructional features, if available during the design process, can be used to design a more efficient simulator. The needed information must convey to the designer the prospective simulator user's concepts of how the device's various instructional features are to be employed during simulator instruction. The problem, then, is to assemble the needed information and to make it available to the designer early in the simulator design process. A convenient mechanism for resolving this problem does not appear to be available at the present time.

PURPOSE

The present paper describes a project in which a solution to the problem identified above was sought. In the project, descriptions were developed of simulator instructional activities associated with a number of instructional features found on current generation flight simulators. The purpose of these descriptions is to document information about the intended use of simulator instructional features for use by simulator designers. Thus, it was intended that design guides would be developed that would provide the mechanism needed to facilitate communication between simulator users and designers and would lead to the development of more efficient simulators.

APPROACH

It might seem desirable to develop a single design guide for each instructional feature. Such guides then could be used in the design of all future simulators. However, such an effort would be comparable to that of seeking a single aircraft, environment, or training objectives model that could be employed in the design of all future simulators. Instead, it was assumed that, while some of the guides would be suitable for a wide range of simulators, others would have to address instructional features and activities that might be specific to major types of simulators. The principal factors of concern that distinguish types of simulators and that could influence instructional feature design are the crew configuration of the aircraft simulated (e.g., single vs multiple-crew positions), the aircraft mission (e.g., transport or attack), the kinds of training intended (e.g., instrument flight, full mission, or procedures), and simulator configuration (e.g., IOS adjacent to or remote from the cockpit, with or without an extra-cockpit visual display).

It was decided to develop the guides for the instructional features of a specific simulator currently under development. This approach would provide a context within which to consider instructional activity alternatives and would afford access to simulator design personnel should their advice be required. At the time the project was initiated, the development of a simulator for the F-16 aircraft was underway. The F-16 is a single crewman, fighter/attack aircraft. The simulator has a one-window visual display and a remote IOS, and it was designed for instrument, intercept, weapons, and limited transition training. Similar simulators will be required for other fighter/attack type aircraft in the future, thus offering the possibility of using and evaluating the instructional feature design guides during the subsequent development of such devices. Therefore, it was decided that the guides would be oriented toward instructional features suitable for a device such as the F-16 simulator then under development.

It was also decided, however, that the guides would not be limited to the proposed design features of the F-16 simulator or of any other existing or planned device. Further, to avoid interference with the F-16 simulator project, there was no attempt to employ the guides being developed to influence the design of the F-16 device. Thus, except for observation of selected F-16 simulator design activities during scheduled Progress Review Conferences and discussions with F-16 simulator project personnel, the present effort proceeded independently of the project in which the F-16 device was being developed.

In preparation for the development of the guides, a number of simulators of recent vintage were inspected, and instructional activities in progress were observed. The purpose of these observations was to take note of both efficiencies and inefficiencies in simulator designs and to determine the apparent rationale underlying the design of the instructional features of these devices. In addition, current fighter/attack training practices in both aircraft and simulators were reviewed so that consideration could be given to the instructional activities involved in such practices during subsequent guide development.

Another factor considered was the learner himself, i.e., the pilot undergoing instruction. The issue was addressed as to whether there were characteristics of pilots, in this case, candidate F-16 pilots, that might require special consideration in instructional feature design. A search of the psychological literature was included in the project to determine whether individual learner characteristics might have implications for design and use of simulator instructional features.

Next, a list was developed of the simulator instructional features for which design guides would be developed. Not all instructional features of the F-16 simulator were included on the list. The list was limited to those features judged to have maximum potential application to other types of simulators as well as to the F-16 device. In addition, instructional features were selected for design guide development that were representative, with respect to function of other instructional features, and thus could serve as examples for the development of guides for such similar features. Several instructional features identified in the F-16 simulator were combined and described in a single instructional feature design guide, because it was judged that they were not likely to be employed independently during the process of simulator instruction, e.g., instructional features involving the recording and on-line playback of both digital and audio data, were treated as a single instructional feature for the purpose of the present project.

Finally, a design guide format was developed. The format was designed to communicate process-of-use information to engineering and other simulator design personnel with little or no knowledge of how training in a simulator is conducted or how instructional features might be employed during that training. The guide format was developed through an iterative process that continued until a format evolved that permitted presentation, both verbally and diagrammatically, of information judged to be needed in order to design an instructional feature with which efficient training could be conducted.

LEARNER CHARACTERISTICS AND SIMULATOR INSTRUCTION

Characteristics of the F-16 pilot candidate population have been investigated by Gibbons, Thompson, Schmid, and Rolnick (1977). These investigators concentrated largely upon demographic data and identified no unique characteristics of that population that were judged to require special consideration in the design or use of simulator instructional features. However, they did note that a wide range of skills will be represented. F-16 pilots will include newly rated pilots as well as highly experienced combat veterans. Such a range suggests that the training to be conducted in simulators such as the F-16 device currently under development will include the acquisition of new skills as well as the refinement of already highly developed ones.

The survey of the psychological literature dealing with learner characteristics examined in particular stylistic cognitive variables that are beginning to be recognized as important in the learning process. While further investigation is needed to clarify the possible impact of stylistic cognitive variables, the concepts underlying these variables place an emphasis on the individual learner rather than on the learning process itself. This emphasis upon the learner suggests a need to examine stylistic cognitive characteristics of pilots to determine whether such characteristics have implications for the way simulator instructional features should be designed or used.

The investigation of the F-16 pilot candidate population conducted by Gibbons, et al, did not consider stylistic cognitive variables, and the distribution of such variables within any pilot

population is not known. However, ten stylistic cognitive variables have recently been identified as potentially important in technical training (Regan, Back, Stansell, Ausborn, Ausborn, Butler, Huckabay, and Burkett, 1978), and several of these would appear to have implications for pilot training as well. One variable in particular, field independence-dependence, appears relevant to instructional activities in a simulator.

The literature suggests that the field independent individual would likely benefit more than the field dependent individual from simulator training which he was largely able to control himself. His success as a learner in a flight simulator would not depend upon an instructor for performance feedback, reinforcement, or direction. Field dependent individuals, on the other hand, would likely be more dependent upon instructor-mediated feedback, reinforcement, and direction during training. In the absence of information to the contrary, it may be assumed that both field independent and field dependent individuals will be found in most pilot groups, including fighter/attack aircraft pilot populations. Therefore, the design of simulator instructional features should accommodate both field independent and field dependent pilots.

From the report by Gibbons, et al, and the survey of the learning literature, several requirements were derived for the planned design guides. First, the instructional feature must accommodate relatively unskilled pilots who are unfamiliar with the tasks to be trained and may need extensive coaching, demonstration, and criterion-referenced feedback concerning their performance. However, these features must also accommodate the relatively skilled pilots who will require little coaching and no demonstration, but much more detailed feedback so that they can hone skills that are already highly developed. Additionally, the instructional features should permit field independent pilots a degree of self-instruction and freedom to evaluate their own performance and to pursue their own perceived needs for further skill development. However, instruction under the direct and structured control of an instructor should also be permitted for the field dependent pilots.

INSTRUCTIONAL FEATURES

Design guides were developed for 12 simulator instructional features. These design guides took into account the learner characteristics identified above. In order to achieve the instructional flexibility required by these characteristics, some of the guides described instructional features that include control and display functions exercisable from the cockpit as well as from the IOS. However, these cockpit functions were limited in order to maintain the degree of fidelity of the cockpit area believed necessary to effective training. All of the guides describe instructional features that can be employed by the simulator instructor to perform coaching, demonstration, feedback, and other instructional functions for relatively unskilled pilots and to conduct highly structured instruction for field dependent pilots. Some of these same instructional features also accommodate the instructional requirements of the relatively skilled pilots and permit pilots to control much of their own instruction, freeing them from dependence on a simulator instructor.

The 12 instructional features for which design guides were developed are identified below, along with a brief description of each.

Record/Playback. Permits the replay of a recent or immediately preceding segment of recorded flight.

Store/Reset Current Conditions. Permits the simulator to be reset by the pilot or the instructor to a situation or set of simulated conditions that existed at an earlier time. It provides a means for rapidly returning to previously encountered events of interest or for repositioning the simulated aircraft for repeated trials of a particular maneuver or maneuver segment.

Remote Display. Permits alphanumeric and graphic data displayed at the IOS to be displayed simultaneously to the pilot in the cockpit. It permits the pilot to review his own performance data and facilitates communication between the instructor and the pilot, particularly when the communication involves reference to graphic or symbolic information.

Hardcopy. Enables the instructor to reproduce on paper perishable information displayed on a CRT at the IOS.

Manual Freeze. Enables the instructor or the pilot to freeze or suspend ongoing simulated activity resulting from actual or recorded input to the aircraft's controls.

Automatic Freeze. Similar to Manual Freeze except that it is initiated automatically, contingent upon specified events (e.g., a crash).

Parameter Freeze. Enables the instructor to freeze one or more of the simulated flight parameters.

Demonstration. Consists of one or more prerecorded aircraft maneuvers to be used as models of the desired performance.

Demonstration Preparation. Enables a simulator instructor to prepare a Demonstration for repeated use during subsequent periods of pilot training. It is a necessary feature if the Demonstration feature is to be incorporated into simulator design.

Malfunction Simulation. Enables an instructor to fail, partially or totally, a simulated aircraft component.

Automatic Malfunction Insertion Exercise. Consists of a training exercise in which simulated

aircraft malfunctions are inserted automatically when previously specified conditions have been met. This feature is representative of a class of automatic training exercises in which a training situation is programmed to occur or is modified contingent upon the occurrence of one or more prior events. The feature design guide itself may serve as a model for the description of other features in which contingent relationships may be established, e.g., target insertion, hostile weapons release, weather modifications, and/or communications/navigation station failures.

Automatic Malfunction Insertion Exercise Preparation. Enables a simulator instructor to prepare an Automatic Malfunction Insertion Exercise for repeated use during subsequent periods of instruction. As with the Automatic Malfunction Insertion Exercise feature, this feature design guide also can serve as a model for other features having similar functional requirements.

FORMAT OF THE DESIGN GUIDES

A six-element format was developed for the instructional feature design guides. Each element is described below.

Feature. Identifies the simulator instructional feature for which the guide was prepared.

Definition. Defines the instructional feature. The intent of the definition is to assure a common understanding of what is meant when a particular feature name is used.

Purpose and Intended Use. Describes the purpose served by the feature in a simulator and the manner in which it is intended to be used by the instructor and/or the pilot during the conduct of simulator training.

Function Description. Describes each function involved in the employment of the instructional feature from its initial accession to completion of its use. While the Function Description is somewhat redundant with Purpose and Intended Use, this guide element isolates and defines more precisely each function associated with use of the feature and specifys relationships among functions.

Concurrent Events. Specifies intended restrictions on feature use, if any, and identifies other simulator instructional features that may be employed concurrently.

Feature Diagram. Diagrams the functions involved in the use of the feature. Each item on the diagram corresponds to a function identified under the Function Description element. The format for the diagram is a flow chart in which each function is presented in the sequence in which it might be performed, and in which each decision required in the use of the feature is represented in binary form.

As an example of the design guides developed during the project, the guides developed for Demonstration and Demonstration Preparation instructional features are presented following the references.

INITIAL DESIGN GUIDE VALIDATION EFFORTS

The purpose of the guides developed during this project is to provide information about how flight simulator instructional features are intended to be used so that such information can be incorporated into simulator design. The extent to which this purpose has been met and will result in the design of more efficient simulators can only be determined after the guides have been used in the design of simulators, and the efficiency of those simulators has been determined during operational training activities. Such an effort will take several years to accomplish. In the meantime, there are more immediate uses to be made of the guides.

Uses to be made of the guides will depend upon the requirements of those who are using them. In most simulator development projects, these uses could include the following:

- Clarifying design requirements. The guides can be reviewed by training personnel for whom the simulator is to be developed to insure that instructional activities and simulator usage are correctly stated. If not, the guides may be revised by these personnel to fit their unique training requirements. Such reviews and revisions should result in clarification of the expectations as well as the requirements of the eventual simulator users.

- Communicating between training and design personnel. The guides provide a convenient mechanism for communicating to the designer the simulator capabilities required by training personnel. The guides might best serve this purpose if they are referenced in simulator performance specifications as an amplification or clarification of requirements for particular instructional features.

- Highlighting simulator design shortfalls. In some instances, the design expectations of training personnel may not be attainable due to cost or technology limitations. In such instances, the simulator designer or developer would be able to identify instructional feature functions specified in the guides that cannot be provided. Training personnel could then assess the impact of such shortfalls and seek alternate instructional activities for use with the device.

- Clarifying simulator testing requirements. The guides can provide a basis for the design of simulator acceptance or operational tests to determine the adequacy of each instructional feature incorporated into the device. The tests could examine individually and in an applications context each function of each feature, and the extent to which use of each feature is compatible with other features that must be used concurrently.

As an initial indication of whether the guides

could be used for any of the purposes indicated above, they were reviewed by personnel involved in the F-16 simulator development project. The reviewers included a former member of the F-16 Instructional Systems Development (ISD) team, who participated in the specification of instructional feature requirements for the simulator and represented the interests of the ISD team in those activities; an F-16 Project Officer from the U.S. Air Force Tactical Air Warfare Center, who represented the interests of the training personnel who eventually will use the simulator; and personnel from the project engineering staff of the developer of the simulator. These reviews were constrained by the fact that the F-16 simulator was already in the manufacturing process and did not incorporate all of the functions described in the guides.

The reviewers were asked to judge whether the guides would have been useful had they been employed early in the F-16 simulator project to clarify the requirements of training personnel, to communicate those requirements to the device designer, and to identify design shortfalls. The expressed judgments of the reviewers were positive, and suggestions were made by the reviewers that resulted in clarification of several feature descriptions. The reviewers were not asked to judge the utility of the guides during future testing of the F-16 simulator, since the device was not designed to comply with the descriptions contained in the guides.

CONTINUING DESIGN GUIDE VALIDATION EFFORTS

Although the guides were prepared specifically for use in the design of a fighter/attack simulator, their utility with respect to other types of simulators is also of interest. The utility of the guides will be partly a function of how easily they may be adapted to other particular efforts. To date, the guides have been used in several simulator design efforts. One of these was the project to develop a simulator for the Army's XM-1 tank. The simulator was intended for training-related research use, rather than for operational training. Several of the guides that describe instructional features relevant to the tank simulator requirements were reviewed with the researchers for whom that device was being developed. The purpose of those reviews was to assess the utility of the guides as a mechanism that would facilitate communication between the researchers and the device developer with respect to the researchers' planned uses of the device, and that would clarify for those researchers' which functions described in the guides could and could not be performed in the simulator as designed. Both uses of the guides appeared to have merit, and modifications to the device's design were initiated as a result of the reviews.

Two additional simulator development projects in which the utility of instructional feature design guides are being assessed have been initiated. Both projects involve flight simulators for the U.S. Coast Guard: one is for the HU-25A twin-engine jet aircraft, and the other is for the HH-65 short range recovery helicopter. The guides developed during the present project which describe instructional features that are to be included in the Coast Guard simulators will be used during the design of those simulators. These guides were modified where necessary to reflect the multi-crew configuration of each aircraft and the configuration of each of the simulators, and to comply with the instructional activities expected to be employed by Coast Guard training personnel. The guides were reviewed by personnel from the Coast Guard's Aviation Training Center to assure that they were consistent with the training requirements of these personnel and with the manner in which they plan to employ the simulators during training. After further revision, the guides were annexed to the simulators' specifications to provide amplification and clarification of instructional feature design requirements identified in the specifications.

In responding to solicitations for the development of the two Coast Guard simulators, each offeror will be requested to indicate any requirements identified in the guides that cannot be met through his proposed design approach. Design shortfalls thus identified will be subjects for clarification conferences with the offerors and with Coast Guard training personnel. The purpose of these conferences, which may result in further revision of the guides or modifications to the proposed design approaches, will be to seek simulator instructional feature design alternatives that will allow the required instructional activities to be conducted in an effective manner. Subsequent simulator acceptance testing activities related to the simulators' instructional features will examine whether each of the functions described in the design guides can be performed under the conditions prescribed for it. The above activities will provide additional information about the utility of the guides.

CONCLUSION

The purpose of a flight training simulator is to permit required instructional activities to take place. The purpose is not for the device to simulate an aircraft, except to the extent that simulation of an aircraft is relevant to the intended instruction. It is inconceivable that one would expect a designer to design a flight training simulator without giving him a great deal of information about the intended instructional activities. Yet, it is apparent from inspection of numerous existing simulators, from review of simulator design procedures, and from review of the relevant literature that designers typically are given very little information about the instructional activities intended to be used with the device they are to design and the functional purposes of those activities.

This situation is believed to be in part a consequence of the lack of a convenient mechanism for assembling relevant information and conveying it to the designer. The purpose of the present project has been to develop such a mechanism. The mechanism developed is a description of the instructional activities to be undertaken in the use of a simulator instructional feature. It is believed

that such descriptions can be used as guides to clarify simulator design requirements, to communicate those requirements to device designers, to highlight design shortfalls due to cost and technological limitations, and to clarify simulator testing requirements.

Twelve design guides for instructional features suitable for a particular type of simulator were developed during the present project. The features were selected in part because of their assumed adaptability to other types of simulators or because they were representative of a type of feature of potentially wide interest. To date, several such adaptations have been made with relative ease. Users of these guides must be prepared to make the necessary adaptations to their particular requirements and/or to prepare design guides for other instructional features where such may be desired for their simulator.

ACKNOWLEDGEMENT

The research described in this paper was sponsored by the Air Force Office of Scientific Research (AFSC), United States Air Force, under Contract F49620-77-C-0112. Maj. Jack A. Thorpe was the contract monitor.

The survey of the psychological literature dealing with the characteristics of the learner was conducted by Joseph H. Grosslight. An earlier version of this paper was presented at the Royal Aeronautical Society Conference, London, England, April, 1979.

REFERENCES

Brown, J. E., Wagg, W. L., & Eddowes, E. E. USAF evaluation of an automated adaptive flight training system (Tech. Rep. AFHRL-TR-75-55). Williams Air Force Base, Ariz.: Air Force Human Resources Laboratory, October 1975.

Charles, J. P., Willard, G., & Healy, G. Instructor pilot's role in simulator training (Tech. Rep. NAVTRAEQUIPCEN 75-C-0093-1). Orlando, Fla.: Naval Training Equipment Center, March 1976.

Gibbons, A. S., Thompson, E. A., Schmidt, R. F., & Rolnick, S. J. F-16 pilot and instructor pilot target population study (F-16 Aircrew Training Development Project Rep. #13, Contract No. F-77-C-0075). San Diego, Calif.: Courseware, Inc., September 1977.

Hughes, R. G., Paulsen, J., Jr., Brook, R., & Jones, W. Visual cue manipulation in a simulated air-to-surface weapons delivery task. Proceedings of the 11th NTEC-Industry Conference, 1978, 95-101.

Isley, R. N., & Miller, E. J. The role of automated training in future Army flight simulators (Final Rep., Contract N61339-76-C-0050). Orlando, Fla.: Project Manager for Training Devices, October 1976.

Regan, T. J., Back, K. T., Stansell, V., Ausborn, L. J., Ausbon, F. B., Butler, P. A., Huckabay, K., & Burkett, J. R. Cognitive styles: A review of the literature (Tech. Rep. AFHRL-TR-78-90(I)). Lowry Air Force Base, Co.: Air Force Human Resources Laboratory, December 1978.

Semple, C. A., Vreuls, D., Cotton, J. C., Durfee, D. R., Hooks, T., & Butler, E. A. Functional design of an automated support system for operational flight trainers (Tech. Rep. NAVTRAEQUIPCEN 76-C-0096-1). Orlando, Fla.: Naval Training Equipment Center, January 1979.

Walsh, M. J., Burgin, G. H., & Fogel, L. J. Tactical performance characterization: Basic methodology (Tech. Rep. AFHRL-TR-78-94). Patterson Air Force Base, Ohio: Air Force Human Resources Laboratory, May 1979.

Feature:

Demonstration Preparation

Definition:

Demonstration Preparation (Demo Prep) is a simulator instructional feature that enables a simulator instructor to prepare a Demonstration (Demo) for repeated use during subsequent periods of pilot training.

Purpose and Intended Use:

The purpose of the Demo Prep feature is to permit Demos to be prepared by recording a period of performance in the simulator, modifying that recording to enhance its instructional value, and adding an expository or instructional commentary. The skills required to prepare a Demo using this feature are those normally found among simulator instructors who are pilots, and no additional technical training or computer programming skills are required. Nevertheless, it is expected that only designated instructors will prepare Demos in order that control may be exercised over Demonstration content and format.

Recording a Demo in the simulator will normally be preceded by the development of a scenario for the Demo. A script of the planned instructional commentary will be prepared and, in addition, the scenario will identify the simulated conditions under which the maneuver(s) of interest will be flown, the number of repetitions of all or designated portions of the maneuver that are to be included in the completed Demo, where Pauses are to appear, and which segments are to be presented in Slow Time. The scenario also will identify the beginning of each Demo segment that is to be directly accessible by the instructor. The script will be edited to assure that proper time relationships will be maintained between the content of the Demo and the related commentary.

Following development of the scenario, with its accompanying audio commentary, the Demo described in it will be developed by flying the simulated aircraft through the maneuver or series of maneuvers to be demonstrated while the flight is being recorded. This process may be repeated until the instructor is satisfied that the maneuver has been flown to the required standards. While making the recording, the instructor (with the assistance of a second instructor located at the IOS) would make use of the simulator's other instructional features such as Freeze, and Store/Reset Current Conditions, as often as necessary to obtain a "model" performance of the maneuver being flown. If the scenario requires that the Demo include more than a single repetition of the maneuver, as usually will be the case, the recording process will be repeated as many times as may be required.

Upon completing the recording of the maneuver, the instructor will "edit" it in accordance with the scenario by inserting Pauses when extended instructional commentary might be required or by "stretching" to Slow Time parts of the maneuver which occur too rapidly in real time for the pilot to be able to see important task interrelationships. He then would add Demo segment identifiers that will permit direct access to the beginning of individual segments when the Demo is employed in the instructional process.

Finally, using the script prepared for that purpose, the instructor will add the prepared instructional commentary to the recorded Demo. Recording the audio, which would normally be done while the newly prepared Demo is being replayed and monitored, will require careful attention--and possibly several practice trials--to synchronize the commentary with the instructional events being commented upon.

Because of limits upon humans' attention span and short-term recall abilities, the more effective Demos will tend to be relatively brief. The subject matter of Demos will consist of complex individual maneuvers or rapidly occurring series of maneuvers of which verbal descriptions alone might not provide enough information for pilots to learn rapidly to perform them. It is not expected that Demos will be prepared to illustrate mission segments in which individual maneuvers are separated by extended periods of relatively simple aircraft control tasks. For these reasons, most Demos, including those which contain Pauses and Slow Time segments, will be of less than five minutes duration. Demos of more than ten minutes would be counterproductive in most instances and should not be prepared.

Function Descriptions:

ENABLE. Preparation of a Demonstration is a function that cannot be performed while instruction is in progress. To assure preservation of previously prepared Demonstrations, and to exercise administrative control over preparation of new ones, the Demo Prep feature cannot be enabled from the IOS.

SET UP SIMULATOR. Setting up the simulator for the task of preparing a Demo, except for the necessary enablement, is comparable to setting it up for an instructional activity. Thus, initial condition parameters which define the flight environment and the aircraft position and status must be selected and entered. After this has been done, the simulator may be flown just as during a period of simulator instruction, and the instructional activity control features of the simulator normally available during such training may be used in preparing the Demo.

RECORD MANEUVER. Upon terminating freeze status, the simulator performance will be recorded as flown. The instructor will fly the maneuvers that comprise the first (or next) portion of the Demo scenario.

REPLAY. After a portion of the Demo is recorded the instructor will use the replay function

to determine if the recording is satisfactory. He may erase and rerecord (i.e., record over) maneuver records that he judges not to be satisfactory.

RECORDING COMPLETED. The recording and replay processes described above will be continued until the instructor has assembled the necessary examples of the maneuver that is the subject of the Demo being developed. The instructor making the Demo may record numerous satisfactory trials sequentially until he has the number of satisfactory trials and variations of trials his scenario requires. For each period of Demo recording he may reestablish the previously selected initial conditions, or a different set of conditions as may be required, to produce a Demo consistent with the scenario.

EDIT. When the instructor has completed recording all of the necessary segments of flight, he will edit the recording as described below to meet the Pause and Slow Time requirements of the scenario.

ADD PAUSE. The instructor will play back the recorded maneuver, and, at points during the playback indicated in the scenario, he will insert periods of Pause. During these periods, the Demo will continue to replay, but the simulated events will be in a suspended or "stop-action" status. Suspending these simulated events without stopping the Demo will permit the later recording of a more lengthy commentary explaining the event than would be possible without Pauses. A Pause may be of any length within the limits of playback time permitted for a Demo.

CHANGE TO SLOW TIME. Segments of the recorded maneuver may be "stretched" from real time to slow time so it will be easier for a pilot to see just what the performance being demonstrated consists of. This stretching will be done, in accordance with the previously developed scenario, by replaying the portion of the maneuver to be stretched while the Change to Slow Time function is exercised. The length of the segment changed to Slow Time is limited only by the total time available for that Demo.

ADD SEGMENT IDENTIFICATION. After all Pauses have been entered and Slow Time conversions have been made, the instructor will replay the Demo (which will now be at its full length) and divide it into independently addressable segments by "flagging" the points at which each such segment is to begin. These "flags" will be located in accordance with scenario specifications and will generally be at the beginning and/or at the end of Pauses and Slow Time segments, and at the beginning of complete cycles of the maneuver being demonstrated.

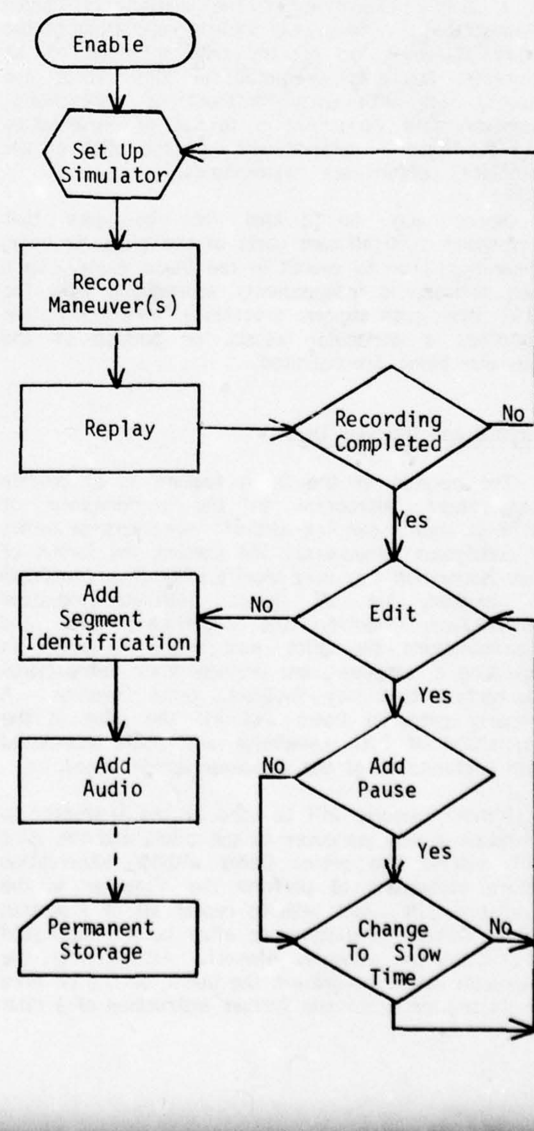
ADD AUDIO. The final task of the instructor preparing a Demo will be to add the instructional commentary. This will be done by reading the script prepared during development of the Demo scenario onto a synchronized tape or other recording medium while the Demo is being replayed and monitored.

PERMANENT STORAGE. When the Demo has been prepared and reviewed by the instructor, and he is fully satisfied that it will provide the instruction intended (i.e., that no further editing or re-recording is required), it will be stored with other Demos for use during subsequent periods of instruction.

Concurrent Events:

While a Demo is being prepared, all simulator controls normally available during periods of instruction will retain their normal functions except those associated with the Record/Playback feature. These controls may be used to create and modify conditions and events that will be included in the recorded Demo. Thus, the instructor may employ the Store/Reset Current Conditions feature, or he may change visibility on the visual display or activate hostile weapons. He also may employ the Hardcopy and Remote Display instructional features and the performance measurement and data summary capabilities of the simulator to examine the maneuver he has just recorded in order to determine its adequacy for his instructional purposes.

Feature Diagram:



Feature:

Demonstration

Definition:

Demonstration (Demo) is a simulator instructional feature that consists of a prerecorded aircraft maneuver, or series of contiguous maneuvers, that provides a model of the desired performance of the maneuver being demonstrated. The Demo reproduces all simulated flight conditions and aircraft performance that occurred when the maneuver was originally recorded, including appropriate actuation of cockpit instruments, indicators and flight controls, motion system movement, visual display scenes, and mechanical and aerodynamic sounds. A Demo includes a synchronized audio briefing, explanation, and instructional commentary designed to facilitate the pilot's subsequent performance of the maneuver.

The content of a Demo is not necessarily limited to a simple execution of the maneuver(s) being demonstrated. A Demo may include repetitions of the entire maneuver or of any one or more of its segments, segments presented in Slow Time, and Pauses, each with unique instructional commentary, whenever such variations in format of presentation may facilitate an understanding by the pilot of the associated performance requirements.

Demos may be divided into segments that correspond to significant parts of the maneuver being demonstrated or to events in the Demo itself. Each such segment is independently addressable from the IOS. Thus, each segment provides a "mini Demo" that addresses a particular aspect or portion of the maneuver being demonstrated.

Purpose and Intended Use:

The purpose of the Demo feature is to provide standardized instruction in the performance of difficult and/or complex aircraft maneuvers or series of contiguous maneuvers. The content and format of that instruction may vary significantly from one Demo to another, but all Demos illustrate idealized performance, identify the significant cues and discriminations the pilot must learn to make in executing a maneuver, and provide other instructional commentary that may facilitate tasks mastery. A properly prepared Demo will aid the pilot in the acquisition of both knowledge and skills associated with performance of the maneuver demonstrated.

Demos normally will be used by the instructor to introduce a new maneuver to the pilot, and the pilot will observe the entire Demo without interruption before attempting to perform the maneuver in the simulator. He might wish to repeat all of a portion of the Demo immediately, or after he has attempted to perform the maneuver himself. Alternatively, the instructor might re-present the Demo, or one or more of its segments, for the further instruction of a pilot who may find the maneuver particularly difficult to understand or to perform correctly. The instructor may re-present only a segment on which the maneuver is recorded in slow time or in which a particular explanation is included. Or, he might repeat the entire Demo or a segment of it with the accompanying instructional commentary off so that he can provide his own commentary.

Function Descriptions:

ENTER. A Demo may be employed through controls located at the IOS at the option of the instructor or the pilot at any time during simulator training. A Demo can only be entered when the simulator is in freeze status.

SELECT SEGMENT. The instructor must select the Demo and the segment (usually the first) of that Demo to be presented, and he must initiate its presentation once the necessary initial conditions have been established. Establishment of the initial conditions for any Demo segment must not require more than 30 seconds.

MONITOR. Once initiated, the Demo will continue to its completion without interruption, change, or instructor or student input unless the instructor elects to turn the audio (sounds and instructional commentary) off, interrupt the Demo temporarily, or terminate it altogether. During the Demo, the instructor and student will monitor it.

AUDIO OFF. The instructor may elect to substitute his own instructional commentary for that provided with the Demo for one or more of the segments. Turning the Audio Off will enable him to do this. During such periods, however, the audio will continue to maintain synchronization with the Demo so that the instructor can reinstate the recorded instructional commentary at any time.

MANUAL FREEZE. The instructor may temporarily interrupt the Demo by initiating a period of Freeze in order to discuss some aspect of it with the pilot or to engage in some other instructional activity. Regardless of prior activities, the instructor may terminate the period of Freeze and continue monitoring the Demo with or without audio accompaniment until its final segment has been completed. Alternatively, he may terminate the Demo at any time and initiate another instructional activity.

COMPLETE. Unless the instructor intervenes, the Demo, once initiated will continue until its final segment has been completed. When that end point is reached, the simulator will automatically revert to a Freeze status with all simulation conditions "frozen" at the values which define the end point of the Demo.

TERMINATE. The instructor may terminate the Demo at any point after its initiation rather than complete it. When a Demo is terminated, the simulated conditions existent at that time, rather than the ones that define the end of the Demo, will

obtain. From those conditions, the pilot may assume control of the simulated aircraft and "fly out," or other initial conditions may be established by the instructor. A Demo will always end or be terminated with the simulation in Freeze status.

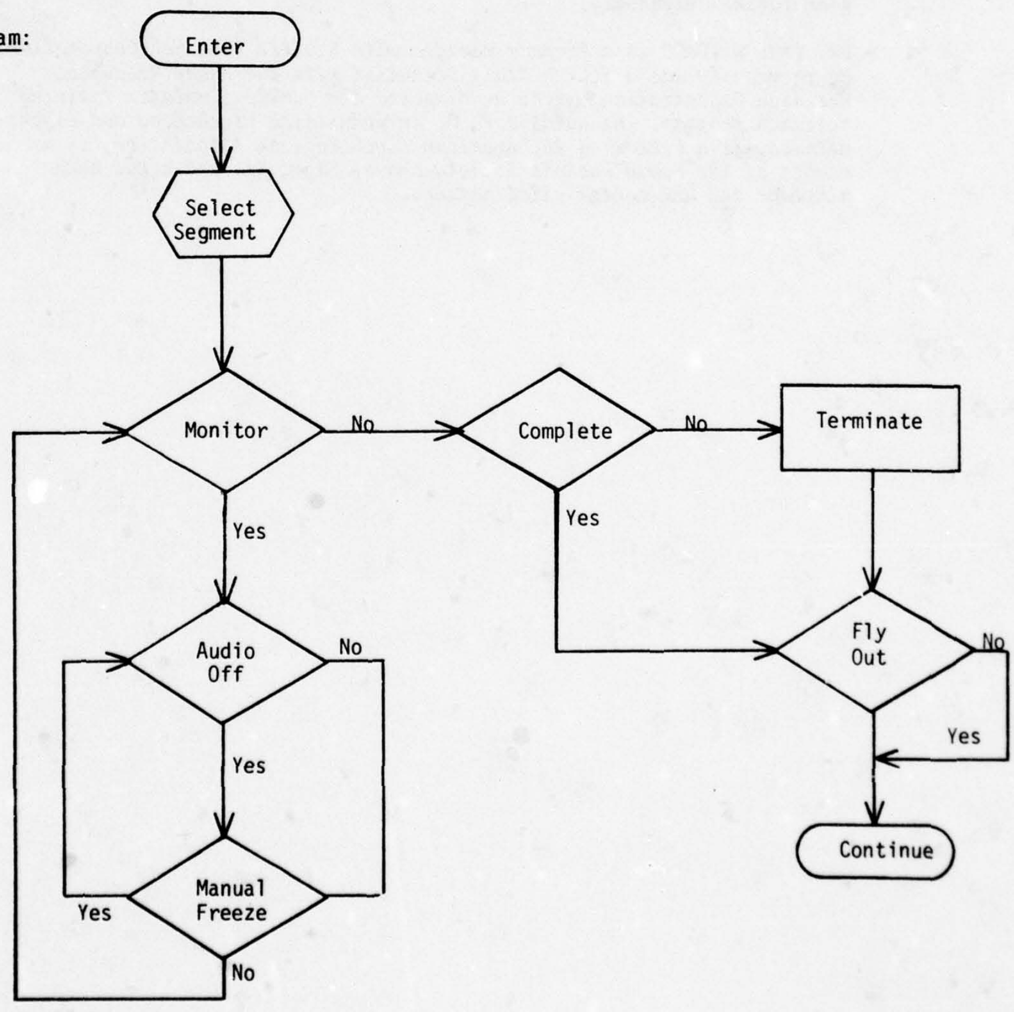
FLY OUT. There will be times when the instructor wishes the pilot to assume control of the simulated aircraft when a Demo has been completed (or terminated before its completion) and to "fly out" from that point. The Fly Out function will permit this to occur.

CONTINUE. Upon completing or terminating a Demo, the instructor may elect to employ any other feature of the simulator in his process of instructing the pilot. Alternatively, he may repeat the same or another recorded Demo or any Demo segment by selecting the desired Demo and segment and repeating the process described above. If he elects this latter course, he retains all options available during the initial Demo presentation, including monitoring the synchronized audio with its instructional commentary. Only a short time interval (e.g., not more than 30 seconds) should be required to re-enter the Demo feature at the beginning of any segment regardless of the point of termination of a Demo.

Concurrent Events:

While a Demo is in progress, the instructor may interact verbally with the pilot in order to contribute to the pilot's understanding of the maneuver(s) demonstrated. He may access previously recorded performance data summaries that will enable him to provide verbal feedback to the pilot concerning his prior performance of the maneuver being demonstrated, and he may index and search data display pages for information that will facilitate the subsequent setup and employment of other simulator instructional features. He may also employ the Remote Display and Hardcopy instructional features, and he may store conditions to which he may wish to reset (using the Store/Reset Current Conditions feature) upon completion or termination of the Demo.

Feature Diagram:



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THE GOOD STICK INDEX
A PERFORMANCE MEASUREMENT FOR AIR COMBAT TRAINING

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SUMMARY

Measuring the proficiency with which a pilot performs a basic fighter maneuver is a difficult task. Many parameters come into play ... the least of which is the frequently used term ... skill. A simulated environment provides an easily managed atmosphere in which to develop and design proficiency measurement techniques, or performance measurements, that may eventually be applied in an airborne environment. This paper reports on one candidate system that has been studied and validated based on the expert opinion of instructor pilots providing air combat training to Tactical Air Command (TAC) Pilots.

INTRODUCTION

The Good Stick Index (GSI) was developed to measure student pilot proficiencies in simulated one-on-one air combat. The GSI, as originally formulated by the Vought Corporation, Dallas, consists of four objective performance parameters measured during TAC Air Combat Engagement Simulator (ACES) I training. The four parameters comprising the GSI were subjectively chosen and, from data obtained over many classes, empirically related to derive a predictor of the "winner" or "runner-up" in the double elimination, one-on-one free engagement tournament held at the conclusion of each training session. This derived relationship predicts the winner or runner-up of the double elimination, free engagement "turkey-shoot" with greater than random frequency.

A study was conducted to statistically investigate the predictive ability of the empirically derived relationship as a predictor of the turkey-shoot winner. These analyses were performed using data collected from 12 classes of students in an experiment representative of TAC ACES I training. Additional analyses were performed to obtain correlations of student pilot background data and IP subjective predictions of student ranking relative to GSI scores and actual turkey-shoot rankings.

BACKGROUND

The TAC ACES I training program is conducted by TAC using the Vought Corporation fixed base air combat simulator, Figure 1. The program utilizes two F-4 configured cockpits with full instruments and weapon systems indicators necessary for air-to-air combat simulation in a functional mode. The software modeling is for F-4D and F-4E aircraft flight characteristics. In addition, a MIG 21 is modeled to provide training in dissimilar aircraft engagements.

The Vought Air Combat Simulator, Figure 1, consists of two cockpits, each situated within a 16-foot-diameter spherical screen. Overhead projectors provide dynamic earth-sky horizon scenes and an image of the opponent's aircraft. The aircraft target is a high-resolution color image provided by the Opaque Target Optical Projector System (OTOPS), recently developed by Vought. Each pilot wears a g-suit and sits on a g-seat. As a pilot increases the load factor on the aircraft, the g-suit inflates and the g-seat deflates. The visual display dims as a function of g and time and finally blacks out, with the target image the last to go. The g-seat also provides a buffet cue, beginning as a high-frequency nibble, increasing in amplitude and decreasing in frequency as penetration into the buffet area occurs.

On-line firing and hit cues, engine, aircraft, and weapon sounds add to the realism of the simulated air combat, and a separate bullet model includes the time of flight. Weapon realism extends to the heat and radar missiles, too, as a miss will be scored if the aircraft target exceeds the missile turning/tracking capabilities before the time of flight has elapsed. A pilot scoring system called the GSI measures the relative air combat skills of the pilot.

A unique Instructor Pilot (IP) station that is mobile and that can be operated from alongside the cockpit provides the IP a matchless vantage point. The IP station provides complete control of the simulation,

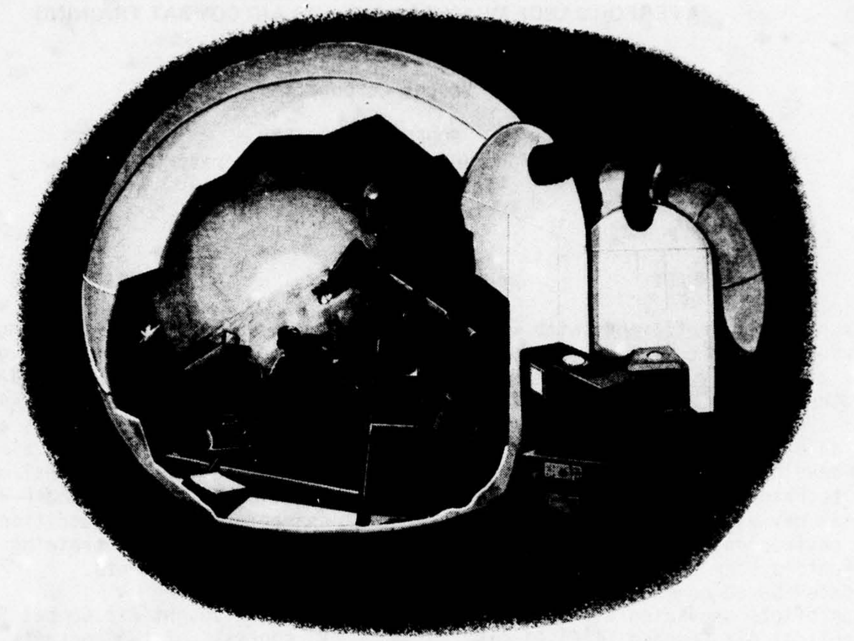


Figure 1. The Vought Air Combat Simulator

including operate, freeze or reset, replay, data recording, video recording, and options to record and play back preprogrammed or canned target trajectories. It also contains the engagement scene which can be recorded on video cassettes, along with the audio from both cockpits and the IP, for subsequent replay and debriefing.

Typically, the TAC ACES I training session is scheduled for one week and consists of eight student pilots and three IPs. Each student accumulates a minimum of 10 hours of classroom and hands-on training in air-to-air combat. Two student pilots train simultaneously in the dual-dome, two-cockpit facility. The student pilot undergoes initial briefings and simulator familiarity sessions on the first day of the 5 days of training. After becoming familiar with the simulator characteristics through the hands-on session, the student is "scored" against a series of canned target maneuvers. The student's initial performance is recorded by computer and stored on magnetic tape.

The final day of training, the fifth day, consists of a second scoring session with each student pilot competing against canned target maneuvers as was initially done on the first day of training. The class training culminates by a double elimination competition, or turkey shoot, where each student competes against the others in one-on-one free engagements until eliminated or a winner is decided.

The data were collected under concisely defined controlled conditions. The study was unique in the sense that the data had to be collected within and from the operational training environment. The collection of data under these conditions also had to be made on a minimum interface and non-interference basis with the ongoing TAC ACES I training program. This requirement precluded the application of experimental controls in a classical sense, as found in a laboratory experiment. As a result, other methods of control were developed to function within the restrictions imposed to provide some assurance as to the fidelity of the data collected and to minimize the effect of undesired variables.

The TAC ACES I students in the study were not aware of the GSI Validation Study and the purposes of data collection. Individual pilot performance data were collected on Monday and Friday of the training week and during the turkey-shoot elimination contest, after completion of the formal

training program. In addition, performance data were collected for four of the 12 classes on Wednesday of the training week.

The Chief Instructor Pilot (CIP) predicted each student's performance based on background information (experiences, training, etc.). Also, when formal training was completed on Thursday, the CIPs ranked each student based on his performance. This ranking, prior to the turkey shoot, training system malfunctions, and other history information, were included in the data collection program.

OBJECTIVES

The scope of the investigation was limited to the optimization and validation of the GSI system. The primary products were assessment of the capabilities and limitations of the GSI scores and the determination of the utility of GSI scores as predictors of pilot performance in the simulated free-engagement, turkey-shoot competition.

The original GSI was statistically validated as to its predictive capability by the use of statistical analysis techniques. An improved GSI predictor, using the four subjectively selected parameters, was obtained by discriminant analyses. A further improved GSI predictor was derived from an expanded list of available candidate predictor variables and variable selection techniques. These improved predictors were cross-validated with data acquired from classes outside the experiment. Confidence intervals on the predictors were provided. Standardized discriminant functions were provided to identify the relative contribution of each parameter in the derived predictor equation(s). Student pilot background and subjective data were input with objective data to obtain optimal predictor models.

Subjective rankings of student pilots were compared to the derived GSI predictors and the actual pilot rankings obtained from turkey-shoot results. These interrelationships were described through the use of correlation and variance/co-variance matrixes.

Data from prior classes were used on a random-selected basis to obtain measures of GSI prediction accuracies. These investigations were necessarily limited to the GSI as determined from the four subjectively selected parameters, since other objective data were not on file. A measure of learning effects was obtained by statistically analyzing data from four classes specifically structured to obtain three scoring periods for each student pilot. Measures of individual and group learning were statistically derived as a function of time in training. These learning rates were compared to student pilot performance data.

The reliability of the GSI was determined by calculating confidence intervals of turkey-shoot rank predictions and corresponding confidence levels of the degree of certainty of the predicted value.

ANALYSES

The GSI score was computed from data acquired during the TAC ACES I training of each class, normally on Monday and Friday. During the GSI Validation Study, a third set of GSI data was collected on Wednesday for four of the 12 classes involved. Data are recorded nominally against five canned targets; generally, two of the five are cinetrack and the remaining three are head-on.

The equation defining GSI is,

$$GSI = 4.6\ (70\text{-}MILERR) + 0.86(PANG) + (O/D\text{-}35) + 0.5\ (180\text{-}TTFK) \quad (1)$$

where:

MIL ERR - average mil error over two cinetrack runs while $R < 3{,}000$ ft.

PANG - average percentage of engagement time in pointing angle advantage, $R < 3000$ ft., over two cinetrack runs.

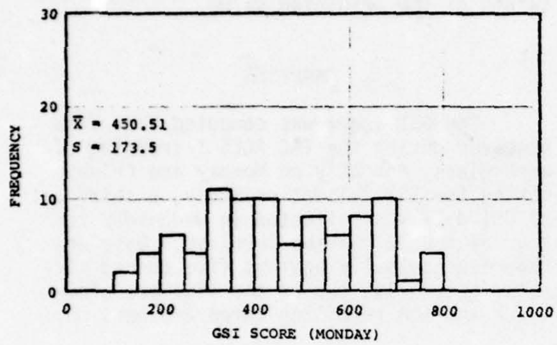
O/D - average ratio of offensive to defensive time against the head-on targets. Offensive time is the time the target aircraft is in the front hemisphere of the piloted aircraft.

TTFK - average time to first kill (seconds) from beginning of run until student achieves first kill against head-on targets with gun or heat missile.

The GSI score has a possible range between zero and 1,000. Each of the four component scores was originally intended to contribute equally to the index. The equation for GSI contains the scaling factors used over the data collection period of this study. MIL ERR, PANG, O/D, and TTFK are referred to as the GSI component scores, or component variables.

The statistical analysis of the Monday and Friday GSI scores and the four GSI component scores collected over the experimental period is presented in this section.

Histograms of the GSI scores and the four GSI component variables (part-scores) were constructed. In general, the score distributions show improvement from Monday to Friday (increase or decrease as appropriate) and the sample standard deviations become smaller (Figure 2).



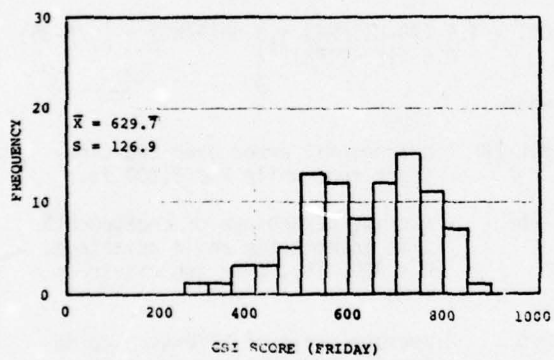


Figure 2. GSI Score Distributions

Correlation coefficients of the four GSI component variables to turkey-shoot rank and fractional wins for both Monday and Friday data are shown in Table 1. The presentation is constructed so that the correlation coefficients for Monday data are shown above the main diagonal of each matrix and for Friday data are below the main diagonal. Relatively strong correlations exist among the component variables indicating non-zero co-variances and thus lack of independence; i.e., possible significant multicollinearities. Correlations between the component variables and turkey-shoot rank and fractional wins are also very weak.

Five three-way analyses of variance were conducted for GSI and the four component variables. The three sources of variation investigated were:

(a) variation between days (Monday and Friday),

(b) variation between turkey-shoot ranks, and

(c) variation between the classes which contained eight students.

Very significant differences existed between Monday and Friday GSI scores, implying, of course, that if GSI measures group learning, a significant increase occurs over the 5-day class period. The other significant source of variation between classes could tend to mask differences between ranks. Scatter diagrams of GSI scores versus turkey-shoot rank showed little significant differences between GSI scores and rank. Analysis of variance for the GSI component variable, average mil error, showed significant differences between ranks but no difference was evident between days. A difference was detectable between classes at the 5-percent confidence level.

The component variable percent PANG showed significant differences between days and between classes. There was no evidence of significance for variation between ranks. The component variable, offensive time, showed significant differences between days. No differences appeared to exist between ranks or classes. For the component variable, TTFK, differences were detected at the 5-percent level between days and between ranks. Differences were not evident between classes.

Table 2 presents a comparison of the best predictor using the Friday only GSI score with random selection and with CIP predictions (CIPPs) made just prior to the turkey-shoot competition. Comparisons were made at four levels of detail as to the outcome of the turkey-shoot. The four levels are defined as follows:

1. Four Groups - Proper placement into the proper turkey-shoot quartile, i.e., 1 or 2 in the first group; 3-4 in the second group, 5-6 in the third group and 7-8 in the fourth group.

2. Upper Half of Class - Proper placement of students in the top four turkey-shoot ranks in those ranks; i.e., 1, 2, 3, 3.5 or 4.

3. Winner and Runner-Up - Proper placement of the winner or runner-up in the winner/runner-up group.

4. Winner - Proper identification of the actual turkey-shoot winner.

TABLE 1 - GSI CORRELATION COEFFICIENTS

MONDAY

	T.S. RANK	AVG.MIL ERR	% PANG	% OFF TIME	TTFK
T.S. RANK	1	.1254	-.1318	-.0270	.1512
AVG.MIL.ERR.	.0200	1	-.0891	-.1915	.1650
% PANG	.0313	-.3071	1	.2107	-.2868
% OFF TIME	-.2761	-.0951	.0007	1	-.5430
TTFK	.2817	.0559	-.1557	-.6052	1

FRIDAY

MONDAY

	FRACT. WIN	AVG.MIL ERR	% PANG	% OFF TIME	TTFK
FRACT. WIN	1	-.1355	.1759	.0261	-.1218
AVG.MIL.ERR.	-.0083	1	-.0891	-.1915	.1650
% PANG	.0289	-.3071	1	.2107	-.2868
% OFF TIME	.2866	-.0951	.0007	1	-.5430
TTFK	-.2748	.0559	-.1557	-.6052	1

FRIDAY

TABLE 2 - A COMPARISON OF FRIDAY GSI RANK PREDICTIONS WITH CHIEF INSTRUCTOR PILOT (CIPP) AND RANDOM SELECTION

GROUPINGS		RANDOM SELECT.	CIPP	GSI RANKING (FRI.SCORE)
FOUR GROUPS (1-2,3-4, 5-6,7-8)	. NO.CORRECT PREDICT.	-	21	26
	. TOTAL NO. PREDICT.	-	67	90
	. % CORRECT PREDICT.	25%	31.3%	28.9%
	. 95% CONFIDENCE INT.	-	20.2-42.5	19.5-38.3
UPPER HALF OF CLASS (1,2,3-4)	. NO. CORRECT PREDICT.	-	24	27
	. TOTAL NO. PREDICT.	-	34	46
	. % CORRECT PREDICT.	50%	70.6%	58.7%
	. 95% CONFIDENCE INT.	-	55.2-85.9	44.5-72.9
WINNER & RUNNER-UP (1, 2)	. NO. CORRECT PREDICT.	-	6	9
	. TOTAL NO. PREDICT.	-	17	23
	. % CORRECT PREDICT.	25%	35.3%	39.1%
	. 95% CONFIDENCE INT.	-	12.6-58.0	19.2-59.1
WINNER (1)	. NO. CORRECT PREDICT.	-	1	3
	. TOTAL NO. PREDICT.	-	9	12
	. % CORRECT PREDICT.	12.5%	11.1%	25.0%
	. 95% CONFIDENCE INT.	-	0-31.6	0-49.5

The CIPPs were made for 67 out of a possible 90 CIPPs. The random-selection probabilities were determined under the assumption of independent random assignment of students to the turkey-shoot position.

Four entries are provided for CIPP and GSI ranking predictors for each of the four groupings. These provide basic data on the actual predictions. For example, for CIPP and the "four-groups" grouping, the CIPs properly placed 21 out of 67 predictions in the correct groupings (1-2, 3-4, 5-6, or 7-8); thus, 21 of 67 or 31.3 percent were correctly classified. Ninety-five percent confidence limits were calculated using these data and were determined to be 20.2 percent and 42.5 percent (1).

Each CIPP and GSI ranking prediction was subjected to a test of the hypothesis that it is equal to or better than random selection (2). The CIPP for the upper half of the turkey shoot was found to be significantly better than random selection for winner and runner-up also at the 5-percent confidence level. All other predictions were found not to be significantly different from random prediction at the 5-percent level. Table 3 provides the levels of significance at which differences would be assumed to exist.

TABLE 3 - APPROXIMATE RISK LEVEL AT WHICH DIFFERENCES CAN BE ASSUMED TO EXIST

GROUPINGS	CIPP	GSI RANKING
FOUR GROUPS	15%	18%
UPPER HALF	5%	13%
WINNER & RUNNER-UP	26%	5%
WINNER	36%	20%

It can be concluded; CIPPs can classify students as to whether or not they will place in the upper half of the turkey shoot with up to 86-percent accuracy. A simple GSI ranking scheme can correctly predict turkey-shoot winner and runner-up classification about 39 percent of the time. For other predictions investigated, the two predictors appear to be no better than random selection.

The Monday and Friday GSI scores, GSI component variables, an expanded set of candidate predictor variables, and demographic data were subjected to a series of

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The Monday and Friday GSI scores, GSI component variables, an expanded set of candidate predictor variables, and demographic data were subjected to a series of

discriminant analyses using the sub-program DISCRIMINANT available as part of the SPSS package (3). The capabilities of this program were useful in the development of improved predictor equations from the available data. The purpose of the analysis was to statistically derive optimal models which predict turkey-shoot rank from data collected during the 12-class TAC ACES I experiment. The derived models used the Wilks' Lambda variable selection criteria to select the best candidate predictor variables from those available. The models derived are optimal within the constraints of the analysis but are not necessarily maximal. A maximal predictor model could only be achieved if all possible models were considered.

Discriminant analysis considers a desire to statistically distinguish between two or more defined groups using information available from sample data. The groupings of interest were defined from turkey-shoot rank. In a normal class of eight student pilots, there are at least five distinguishable turkey-shoot groupings. These are, in order from most favorable to least favorable outcome: winner (1), runner-up (1), third eliminators (2), second eliminators (2), and first eliminators (2).

The primary objective of the analysis was to develop predictor algorithms for turkey-shoot winners; therefore, the groupings considered were structured to investigate the level of detail at which winners could be predicted from available data. Winners were classified in two ways. One winner class was the absolute winner, or undefeated student, in the turkey shoot. A second winner class was the winner and runner-up. This grouping scheme was used with some limited success in earlier Vought investigations which employed only the Friday GSI score as the predictor variable. In all, four different grouping schemes (winners, winners and runners-up together, the upper half of the class, and quartile groupings) were defined and investigated.

The analysis to obtain an improved GSI was conducted in four parts, each part being defined by the candidate predictor variable set to be used. The first analysis used Monday and Friday GSI scores as candidate predictor variables. This analysis provided a measure of the best prediction capability of the GSI score.

The discriminant analysis correctly classified most of the true winners but incorrectly classified a relatively large number of non-winners as winners. By using indicators more complex than the composite GSI score, it was possible not only to correctly classify winners a fairly large percent of the time, but also to greatly reduce the incidence of non-winners improperly placed into the winners' group.

In the second analysis, the four component variables (or part scores) from which GSI is calculated were used instead of the composite GSI scores. The DISCRIM program was then allowed to select from these eight component variables (four for Monday and four for Friday) the best predictor variables for each of the four classification schemes. The eight variables are defined in Table 4 which shows that DISCRIM was selective and did not use all available data to define the optimal prediction (classification) equations.

TABLE 4 - MONDAY AND FRIDAY GSI COMPONENT VARIABLES AND VARIABLE SELECTION BY DISCRIMINANT GROUP

VAR. DESIG.	GROUP I - Winners; GROUP II - Others	GROUP I - Winners & Runners-Up; GROUP II - Others	GROUP I - Winners, R.U., & 3rd Elim.; GROUP II - Others	GP. I - Win. & R.U.; GP. II - 3rd Elim., GP. III - 2nd Elim.; GP. IV - 1st Elim.	VARIABLE DEFINITION
X1		X		X	AVERAGE MIL ERROR FOR FRIDAY
X2		X			PERCENT TIME IN PANG FOR FRIDAY
X3	X		X	X	PERCENT OFFENSIVE TIME FOR FRIDAY
X4		X	X		TIME TO FIRST KILL ON FRIDAY (SECONDS)
X5		X		X	AVERAGE MIL ERROR FOR MONDAY
X6					PERCENT TIME IN PANG FOR MONDAY
X7					PERCENT OFFENSIVE TIME FOR MONDAY
X8	X		X	X	TIME TO FIRST KILL ON MONDAY (SECONDS)

Results of the Discriminant Analysis

In the discriminant analysis where Monday and Friday GSI scores are the predictor variables, members of the first group are correctly classified in the order of 60 percent of the time, but many non-first group students are classified incorrectly in the first group. The lack of discriminant power was evidenced by low values of the canonical correlation coefficients of the respective discriminant functions; i.e., between 0.120 and 0.218.

The eight GSI component variables (four for Monday GSI component scores and four for Friday GSI component scores), when used as candidate predictor variables, resulted in better predictive capabilities than in the GSI score analysis.

Candidate predictor variables were developed from an objective data set collected during the Monday and Friday GSI scoring session but not previously analyzed.

In the expanded data-set analysis, over 80 predictor variables were available for consideration as candidates for the analysis. An initial screening of the complete list was necessary to reduce the number of variables to an acceptable size. This screening was accomplished by correlating all variables with turkey-shoot rank and then selecting the 40 variables from the list with the greatest correlation coefficients. Table 5 shows those objective variables which were selected by DISCRIM as the best turkey-shoot rank predictors. In this table, the predictor variables were separated by day of data collection. The discriminant classification schemes by which each were used is also indicated. Use of this expanded list of candidate variables appears to have generally improved the winner prediction capability.

The canonical correlations of the discriminant functions of the analyses greatly increased over analogous functions in the previous analysis, indicating increased capability to discriminate between groups. This increased discriminant capability is at the cost of increased complexity in the number of variables required and the complexity of calculations. The classification functions provided optimal predictors for the objective data analyses and included the best predictor variables consistent with the Wilks' Lambda variable selection criteria. The analyses provided correct classification into Group I on the order of 80 percent; however, a fairly large number of non-Group I members were misplaced.

The analysis used as candidate predictor variables all of the objective data set plus seven demographic variables. Comparison of the results with the expanded objective data analysis showed predictions to be as good or better than before. Mis-classification into Group I was reduced in three of the four classifications, and correct classification into Group I was improved slightly in two of the four classifications. Evidence of this improved discrimination was provided by improvements (increases) in the canonical correlations of the discriminant functions.

In the first discriminant classification scheme (Group I - Turkey-Shoot Winners, Group II - Other), the number of predictor variables required to maintain a constant correct classification rate was reduced from 11 to 10 by inclusion of demographic data.

Inclusion of the demographic data with the expanded objective set caused several Monday objective variables to be excluded in

TABLE 5 - SELECTED OBJECTIVE DISCRIMINANT VARIABLES

VAR. DESIG.	WINNER VS OTHERS	WIN/R.U. VS OTHERS	UPPER 1/2 VS LOWER 1/2	FOUR GROUPS	VARIABLE DEFINITIONS
M4			X		TOTAL FUEL USED (LBS./AVG./HEAD-ON)
M8	X				TOTAL ROUNDS FIRED (NO. TOTAL/HEAD-ON)
M9				X	TOTAL TIME SR LT 1500 (SEC-AVG./CINETRACK)
M10		X			AVG. MIL. ERROR SR LT 3000 (MILS-AVG./CINETRACK)
M11				X	TIME TO PANG (SEC-AVG./CINETRACK)
M12	X				TIME TO FIRST KILL (SEC-AVG./HEAD-ON)
M14		X			DELTA ENERGY STATE - CINETRACK (INT. - END/CTK)
M16	X				TOTAL NO. HITS - CINETRACK (HITS/CTK)
M20			X		TOTAL TIME IN R-MIS ENVELOPE - CTK (TIME/CTK)
M22				X	TIME TO GUN ENVELOPE - CINETRACK (TIME/CTK)
M24		X			TOTAL TIME IN GUN ENVELOPE - CTK (TIME/CTK)
M25			X	X	TOTAL TIME IN GUN ENVELOPE - HEAD-ON (TIME/H.ON)
M29	X	X			HIT/MISS HEAT - MIS. SCORE - H.ON (H*(H+M)/H.ON)
M32	X	X		X	HIT/MISS GUN SCORE (H*TOTAL RDS/H.ON)
F1			X	X	MAX G'S (MAX/SERIES)
F11	X				TIME TO PANG (SEC-AVG./CINETRACK)
F16				X	TOTAL NO. HITS CTK (HITS/CTK)
F18	X	X	X	X	TOTAL TIME IN H-MIS. ENV. CTK (TIME/CTK)
F22	X				TIME TO GUN ENVELOPE CTK (TIME/CTK)
F23	X			X	TIME TO GUN ENVELOPE H.ON (TIME/H.ON)
F25			X	X	TOTAL TIME IN GUN ENVELOPE H.ON (TIME/H.ON)
F27	X	X		X	G-SPREAD H.ON (MAX. G-MIN G)
F29	X	X	X	X	HIT/MISS H-MIS SCORE H.ON (H*(H+M)/H.ON)
F30			X		HIT/MISS R-MIS SCORE H.ON (H*(H+M)/H.ON)

the resulting algorithm.

Comparison of Prediction Results

Table 6 summarizes the predictive capabilities of the major predictor models presented. The table also includes approximately 95 percent confidence limits on the prediction rates (4). Note that the confidence limits are approximate and use the normal approximation to the binomial. This requires a relatively large sample size. For predictions of the winner (the last row of the table), sample size is nine or 12.

Given the predictor models developed using discriminant analysis, it is necessary to test these models using data collected outside the experimental data set. The purpose of these tests is to determine if the predictability of the developed models is retained using predictor variable data not used in the calculation of the parameters or in the selection of the predictor variables. In the analysis performed, there is evidence that the parameters selected are very sensitive to the particular data set used in their estimation and to the definition of the discriminant groups. The values of the parameter estimates are also probably quite sensitive to the data set used.

A very limited test analysis using data obtained prior to this study has been conducted on the predictor models developed from Monday and Friday GSI scores and Monday and Friday GSI component variables. No additional test analysis was conducted.

PSYCHOMETRIC AND EDUMETRIC DATA ANALYSIS

Edumetrics is defined herein as the measurement of an individual's gains from training experiences by the quantitative assessment and analysis of performance data, to include individual and group data. Edumetrics is shown to be concerned with measures of learning performance in contrast to psychometrics, which is concerned with the measurement of individual differences (i.e., measures of individual innate abilities and traits).

Individual and group performance data were recorded for the 80 subjects in this study. The mean GSI performance scores for the Monday and the Friday data sessions were calculated for each of the 12 classes. Two least-squares linear-trend lines were computed, using the Monday GSI scores and the Friday GSI scores.

Four of the 12 TAC ACES classes in this study were subjected to separate analysis. In addition to the normal TAC ACES Monday and Friday data collection sessions, GSI performance data were recorded on Wednesday of the training week. This yielded three sets of performance data for each of the four classes. Scatter diagrams, linear and quadratic curves, and frequency distributions were constructed. A total of 81 data points

TABLE 6 - COMPARISON OF PREDICTION RESULTS

					DISCRIMINANT ANALYSIS			
GROUPINGS		RANDOM SELECTION	CIPP	GSI RANKING (FRI. SCORE)	GSI SCORE MON. & FRI.)	GSI PRED. VAR.	EXP. LIST	EXP. LIST +DEM. VAR.
Four Groups (1-2, 3-4, 5-6, 7-8)	. No. Correct Pred.	-	21	26		36	56	57
	. Tot. No. Pred.	-	67	90		90	89	89
	. % Correct Pred.	25%	31.3%	28.9%	N/A	40.0%	62.9%	69.3%
	. 95% Conf. Int.	-	20.2 - 42.5	19.5 - 38.3		29.9 - 50.1	52.9 - 73.0	54.1 - 74.0
Upper Half of Class (1,2,3,4)	. No. Correct Pred.	-	24	27	27	27	36	37
	. Tot. No. Pred.	-	34	46	46	46	46	46%
	. % Correct Pred.	50%	70.6%	58.7%	58.7%	58.7%	78.3%	80.4%
	. 95% Conf. Int.	-	55.2 - 85.9	44.5 - 72.9	44.5 - 72.9	44.5 - 72.9	66.3 - 90.2	69.0 - 91.9
Winner & Runner-Up (1, 2)	. No. Correct Pred.	-	6	9	14	15	19	19
	. Tot. No. Pred.	-	17	23	23	23	23	23
	. % Correct Pred.	25%	35.3%	39.1%	60.9%	65.2%	82.6%	82.6%
	. 95% Conf. Int.	-	12.6 - 58.0	19.2 - 59.1	40.9 - 80.8	45.8 - 84.7	67.1 - 98.1	67.1 - 98.1
Winner (1)	. No. Correct Pred.	-	1	3	8	9	10	10
	. Tot. No. Pred.	-	9	12	12	12	12	12
	. % Correct Pred.	12.5%	11.1%	25.0%	66.7%	75.0%	83.3%	83.3%
	. 95% Conf. Int.	-	0 - 31.6	0 - 49.5	40.0 - 93.3	50.5 - 99.5	62.2 - 100	62.2 - 100

were used to fit linear and quadratic least-square lines for all four classes in the sample. Both the linear and the quadratic equations developed approximate the centroid of the mass of data points for each pilot, Figure 3. Linear and quadratic lines fit the data well. Objective measures of these fits are shown in the edumetric analysis. The quadratic curve is preferred in describing the data because it approximates true learning rates, which tend to be non-linear as a function of time. Here, it specifically shows a higher rate of learning during the early phases of training and a lower, slower rate during the final training phases. The distribution of the GSI scores by day of training are shown characterized by normal distributions in Figure 4. It can be seen that the mean ($\overline{X}$) GSI scores improved with length of training.

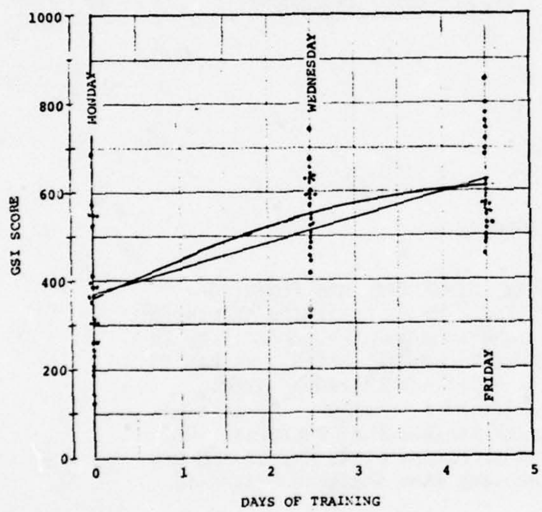

Figure 3. Scatter Plot of GSI Scores.

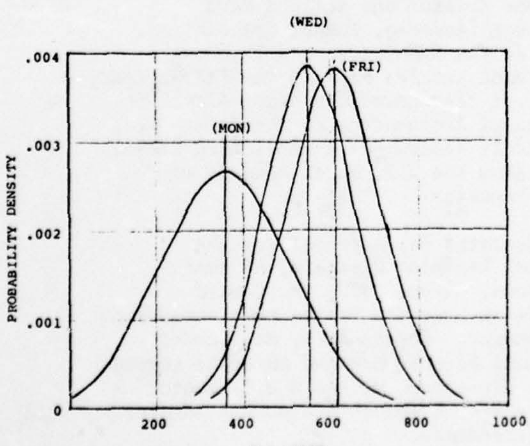

Figure 4. GSI Score Densities

The standard deviation of the scores decreased as length of training increased. This would indicate the effects of learning. The reduced variability in the Wednesday and Friday Standard Deviation values suggests that the subjects were using their experiences gained during the first 2-1/2 days of training and calibrating their performance responses to the expected and anticipated performance of the canned targets.

The degree of individual change in performance score for each subject in this sample over the 4.5-day training week indicates the individual subjects had a mean performance score (GSI) improvement of 61.3 percent for the 27 subjects in the sample.

Using performance data collected on Wednesday for four of the 12 classes, the method of analysis was to fit a straight line and a quadratic curve through the data. The objective was to ascertain the general trend n GSI scores as a measure of group learning rates as the classes progressed.

A scatter diagram of the GSI scores versus days of training shows the linear and quadratic least-squares curves fit through the data. Both curves can be seen to fit well through the central regions of the data for each day. Each fit shows the general trend of GSI Score increasing with days of training.

A further point of interest is the actual normality of the distributions of the GSI scores being analyzed by day; that is, is there any reason to doubt that a given set of scores is normally distributed? The Kolmogorov-Smirnov (K-S) test of goodness of fit was applied to GSI scores for each day. (5). The scores were found to be normally distributed at the percent significance level for each of the three sets of GSI scores.

CONCLUSIONS AND RECOMMENDATIONS

As a candidate technique for simulated ACM performance measurement, the GSI has been analyzed using data from a control group to validate the potential for predicting and ranking students in the TAC ACES I Training Program. The GSI, developed from empirical data, predicts student pilot performance comparable to the predictions of ACM experts ... the instructor pilots. This study examined available historical data demonstrating the value of documenting professional background (experience), student performance results, and instructor evaluations as baseline data for formal training courses.

Failure to collect ample data on training experiences can impact on future potential to account for training expenditures (accountability) and end results (effectiveness).

The GSI has been shown to predict student pilot ranking, in the TAC ACES I training program, with 75 percent accuracy. By adding available objective and subjective data, the prediction improved 80 percent. Such measures, in a simulated environment, have potential training value in the dynamic setting of airborne engagements using the data transmission capabilities of an automated range.

It follows that if a measurement can predict training outcomes, then the measurement parameters must be good indicators of performance. Systems like the GSI should be applied to available simulators and to an air-combat maneuvering range toward developing an objective measure of transfer of ACM training to the airborne mission. This next step is the logical order for moving automated performance measurement of ACM skills to the live-battle scene.

REFERENCES

1. Ostle & Mensing. Statistics in Research, (3rd ed.). Ames: Iowa State University Press, 1975, 100-101.

2. Ostle & Mensing. Statistics in Research, (3rd ed.). Ames: Iowa State University Press, 1975, 129-133.

3. Nie. Statistical Package for the Social Sciences (SPSS), (2nd ed.). New York: McGraw Hill, 1975, 434-462.

4. Ostle & Mensing. Statistics in Research, (3rd ed.). Ames: Iowa State University Press, 1975, 100-101.

5. Ostle & Mensing. Statistics in Research, (3rd ed.). Ames: Iowa State University Press, 1975, 489-490.

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SPACE SHUTTLE SINGLE SYSTEM TRAINER

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ABSTRACT

The Space Shuttle Single System Trainer was developed to enable more effective use of available training time on the Shuttle Mission Simulator by off-loading basic systems training from the mission simulator. In comparison to the mission simulator, the trainer is a low-cost interactive systems trainer using two medium fidelity student stations, each containing the Orbiter forward and aft flight deck displays and controls. These student stations are interfaced with application programs in a minicomputer to provide a realistic flight training environment. The trainer math model fidelity enables the use of normal mission checklist and malfunction procedures in operating the Orbiter systems. The trainer provides systems level operations and skill training to Shuttle flight crews, flight controllers, and flight operations support personnel on a single Orbiter system basis. Display and control familiarization, normal operation and malfunction procedure training are completed in the trainer in preparation for all-up flight crew training in the mission simulator.

INTRODUCTION

Early in the development phase of the Shuttle Mission Simulator (SMS), Flight Operations Directorate management at NASA Johnson Space Center (JSC) recognized that the time required for student training on the SMS would significantly exceed the time available. The Crew Training and Procedures Division (CTPD) was tasked to develop cost-effective support training systems in order to reduce the load. This task assignment resulted in the design, development and implementation of the Single System Trainer (SST).

During SST task analysis and requirements development, CTPD personnel determined that the SST could be developed inhouse at considerable cost savings. The student station structures, as well as the control and display fabrication drawings, were developed within the CTPD. The JSC Operations Directorate fabricated the two student stations. After the computer system requirements were defined, Ford Aerospace & Communication Corporation (FACC) was contracted to purchase the computer systems and design the student station/computer interface.

SST software was developed at JSC by Civil Service and FACC programmers. The software development was unique in that the programmers interfaced directly with the instructors who would ultimately conduct the training on the Orbiter support systems in the SST. The close working relationship that developed resulted in a basic systems trainer without unnecessary frills and with a minimum of discrepancies.

Prior to availability of the SST, flight crews in training went directly from classroom training to the mission simulators. Since initial simulator sessions were devoted only to location and familiarization with the operation of the various controls and switches, this approach did not use the full capabilities of the mission simulator effectively. With the SST, however, classroom sessions are immediately followed by practice sessions in the trainer, which reinforces the lecture and provides students experience in basic system operation during their first simulator sessions.

Students move on to the SMS when those skills are perfected and ready to be exercised in the larger environment of the SMS. Approximately 56 hours of training for each individual flight crew member is off-loaded from the SMS to the SST. In addition to reducing the SMS training load, this allows more efficient use of the available SMS time in all-up or integrated training operations; since members of the flight crew, trained separately in the SST, can be trained together in the SMS.

More efficient training of flight controllers and simulator instructors is also accomplished with the SST. Prior to availability of the SST, flight controllers in training went directly from classroom training to the Mission Control Center (MCC). Now, with added SST training, flight controllers become familiar with what the flight crew must do in operating the system and what physical movements are necessary in performing the Orbiter system operating procedures. This avoids flight controller requests from the MCC for action that is physically impossible because of the crew member's current activity or location in the Orbiter cabin. Simulator instructors, some of whom are SST instructors, reinforce their knowledge of Orbiter systems as they conduct the SST training exercises.

Since SST training operations were initiated 3 July 1978, the trainer has received very favorable acceptance by both students and instructors.

GENERAL DESCRIPTION

The SST consists of two student stations, a minicomputer system, two instructor stations, digital conversion interface equipment and an intercom system. The SST is capable of providing training on two Orbiter systems simultaneously, one from each student station. Currently, the following Orbiter systems are instructed in the SST:

- Station 1
  - -- Orbital Maneuvering System/Reaction Control System
  - -- Communications
  - -- Instrumentation
  - -- Navigational Aids.
- Station 2
  - -- Electrical Power System
  - -- Environmental Control and Life Support System
  - -- Auxiliary Power Unit/Hydraulic
  - -- Structures/Mechanical
  - -- Caution and Warning System.

The SST represents an economical match of the training requirements and the training facility. Since each station supports only certain systems, controls and displays not used for operating those systems can be represented by photographs or other graphics.

Some of the features of the SST include:

- Correct geometry and eye angles for all cockpit panels
- Ability to use normal flight procedures and checklists
- Realistic response to onboard control inputs
  - -- Control inputs in less than one second
  - -- Cathode-ray tube update in less than two seconds
- Interaction with the EPS for simulated loads
- System initialization with all temperatures, pressures and electrical loads at normal values
- Functional operational alarms for all systems
- Functional simulation of the Orbiter data processing system for systems management, limit sensing, systems control, data display and remote monitoring
- Training record files maintenance as a background task.

The Crew Software Trainer (CST) is a recent addition to the SST. This is a part-task trainer used to train the flight crew in onboard software structure, interfaces, and displays, and use of the keyboard and syntax. The CST, previously a separate device, was incorporated into the SST to provide additional data processing capability for the CST models. CST training exercises are prerequisites for Orbiter system training exercises.

TRAINER OPERATIONS

The Orbiter systems taught in the SST follow a lesson sequence of display and control familiarization, normal system operating procedures and system malfunction operating procedures.

The display and control communications and instrumentation presentations are on audio tape. Toggle switch control is provided so the student can advance the lesson as various displays and controls are located or as directed by the instructor. The remaining operations lessons and all of the malfunction lessons are conducted by the instructor who monitors the student's progress via the training script and at appropriate times, requests him to perform various system operating tasks or to implement malfunction procedures in response to system failures. These system failures are inserted by the instructor using the instructor station computer terminal which is located with the student station. The instructor can also observe the student's progress, answer any questions the student may have, and provide assistance as necessary. This one-on-one training promotes a close relationship between the student and instructor and results in a dialogue that continues after the training session ends.

The SST provides an environment for high-learning efficiency and retention in operating the Orbiter systems. According to the flight crew, when the SST was incorporated into the system, their learning curve went straight up as compared to instruction given only in a classroom environment. Student interaction with the system is given as the principal cause.

SST functional representation of the systems also enables the development and verification of procedures and checklists, particularly malfunction procedures. Here, the ability to interact with system hardware and software provides a catalyst for indepth procedure reviews.

Currently, 72 hours per week of training are scheduled on the SST with a 96 percent trainer uptime. This uptime figure results from the inhouse experience in SST hardware and software engineering that allows an immediate response to problems by the engineer/instructor team.

SST SYSTEM ENGINEERING

The SST hardware and software elements were specifically designed to support the following functions:

- Simulation of Shuttle flight deck control, indicator, and display instrumentation in appropriate vehicle orientation
- Conversion of the flight deck control, indicator, and display instrumentation to computer-compatible input and output
- Simulation of vehicle system operations via programmed model execution
- Simulation of Shuttle intercom and air-to-ground voice communications
- Instructor communication, monitoring and malfunction control facilities
- Support of four concurrent training exercises: two SST and two CST exercises.

These functions have been implemented to a medium degree of fidelity by using close facsimiles of the onboard panels arranged in proper orientation for student manipulation during training exercises; a 10-times-per-second execution of the models driving the SST instrumentation; and an extensive malfunction insertion capability provided to instructors for both hard and soft failure of system instrumentation.

SST HARDWARE DESIGN

SST hardware design is based on the functional definition of six major hardware elements. These elements are:

- Student Station Complex (SSC)
- Instructor Station Complex (ISC)
- Central Computer Complex (CCC)
- Digital Conversion Equipment (DCE)
- Intercom Subsystem
- Crew Software Trainer (CST)

A block diagram of the SST hardware system is shown in figure 1. The performance characteristics of each of these elements are described in the following paragraphs.

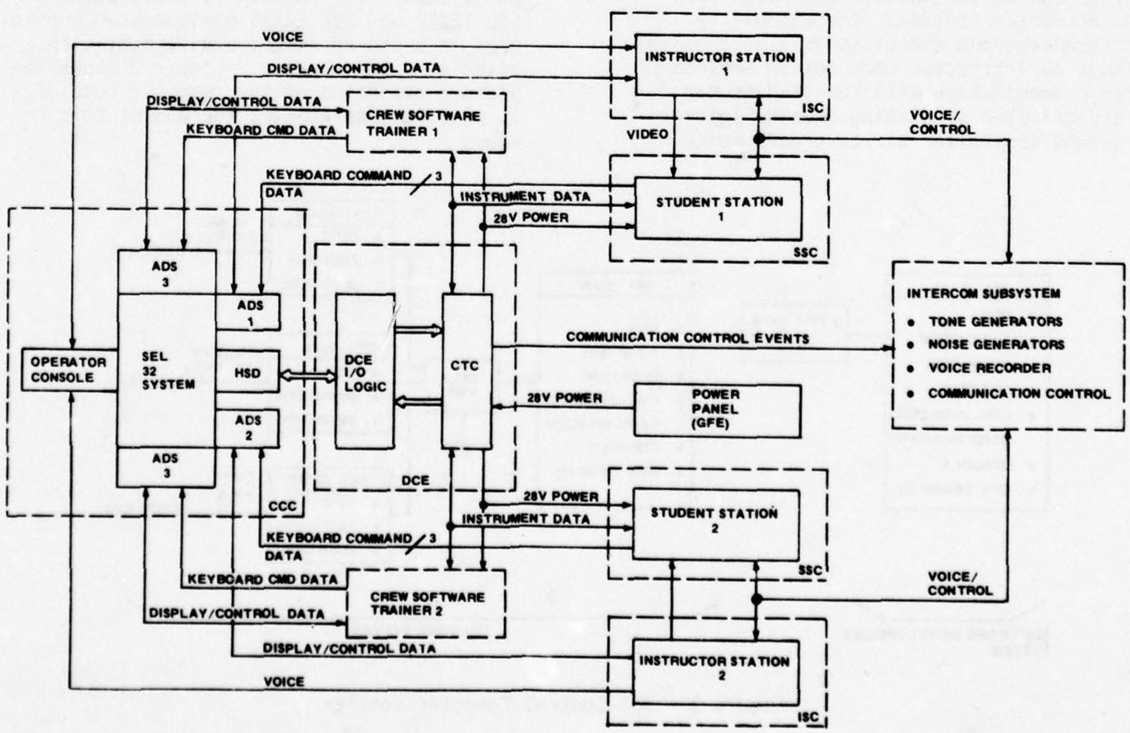

Figure 1 - SST Hardware System Block Diagram

STUDENT STATION COMPLEX (SSC)

The SSC consists of two student stations designated 1 and 2. Each of these stations is a fabricated wooden frame into which the flight panels have been installed in proper orientation as shown in the photograph opposit (figure 2). The flight panels have been fabri cated using actual vehicle dimensions and closely resemble the actual onboard panels. All wiring between each panel and the digital conversion equipment has been pigtailed from each of the components to a connector. This technique allows easy removal of individual panels for modification or component replacement.

INSTRUCTOR SYSTEM COMPLEX (ISC)

The ISC consists of two instructor stations designated 1 and 2. Each station is co-located with its associated student station for instructor control and monitoring of training exercises in progress. This control and monitoring function is performed by the instructor through an interactive graphics terminal which is used to communicate with the active system model. The ISC also provides for voice communication with the student. The instructor may, using this terminal, monitor displays and enter malfunctions into the system. In addition, all system models appropriate to the student station can be initialized and reset from the instructor station. The capability for tape recorded exercises is also available so that an instructor need not be present. Voice communication with the student may be accomplished simulating onboard intercom or ground controller air-to-ground voice.

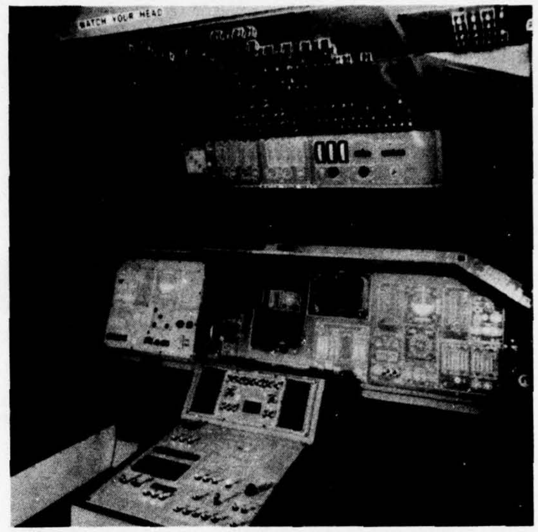

Figure 2 - SST Student Station

CENTRAL COMPUTER COMPLEX (CCC)

The CCC is the processing element of the SST system. The complex is composed of a SEL 32/77 and SEL 32/55 minicomputer configured in a shared memory environment with associated peripherals. Figure 3 shows the planned expansion of the computer complex. It will be completed by the end of this year.

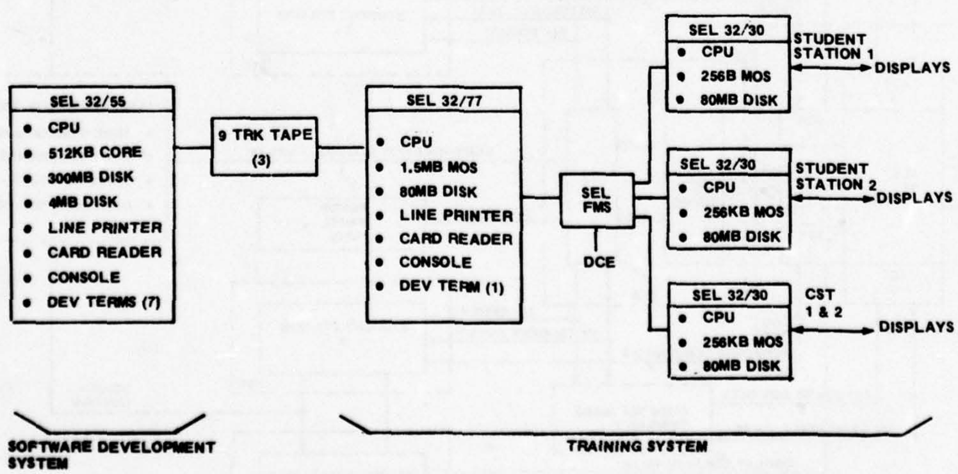

Figure 3 - SST Central Computer Complex

DIGITAL CONVERSION EQUIPMENT (DCE)

The DCE is a custom-built hardware element which interfaces the SST instrumentation to the CCC. The capabilities of this device include:

- Fielding alternate action, momentary action and thumbwheel switch inputs
- Driving digital and analog outputs
- Formatting input and output data from and to the CCC, high-speed access to the CCC.

This unit is housed in a single EIA standard 19-inch cabinet, and is capable of interfacing 2560 switch closure type inputs, 2000 digital outputs and 80 analog outputs with 8 bit resolution. The DCE block diagram is shown in figure 4.

The formatting capability allows for switch data to be automatically transferred to the CCC on byte boundaries with one, two, four, or eight bits significant. This technique allows for the elimination of bit manipulation instructions, clustering of input events, and Binary Coded Decimal (BCD) inputs. The formatting capability also allows the CCC to output data on byte boundaries with one, two, four, or eight bits significant. This input technique eliminates the need for bit manipulation instructions and allows for clustering of output events and 8-bit digital to analog outputs.

The interface capability from/to the DCE and the CCC is 32 bits parallel and is essentially direct memory access. The input/output (I/O) time for the current SST configuration is less than 1 millisecond (msec) per transfer. Interface is program-controlled, versus interrupt-driven, to facilitate program execution. A scheduler program initiates a DCE I/O pair every 50 milliseconds. This means that the instrumentation is being sampled and updated at a rate of 20 times per second.

The DCE also provides for the concentration of the instrumentation signals to and from the DCE through the use of a cable termination cabinet. This technique allows the I/O of the DCE unit itself to be very dense. The current DCE provides termination for 4720 signals. The I/O from the cabinet is also arranged so that an I/O connector is dedicated to a card slot. This allows for the rearrangement of the input and output buffers without wiring modification. In addition, these modifications can be accommodated at the cable termination cabinet. The cable termination cabinet also provides for demarcation between the CCC and the SSC for the purposes of troubleshooting failures.

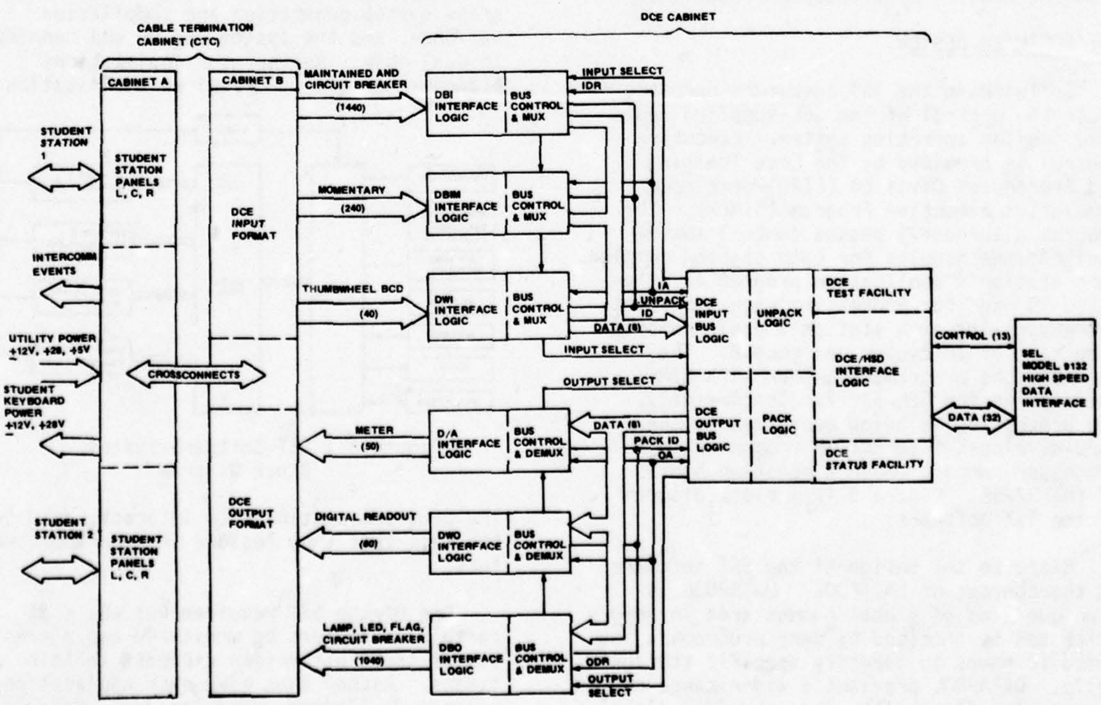

Figure 4 - Digital Conversion Equipment Block Diagram

INTERCOM SUBSYSTEM

The Intercom subsystem is also a custom built hardware element which provides the voice loops necessary for communication between the student and the instructor, and between the instructor and CCC. Communication equipment in Student Station 1 provides for headset operations in either push-to-talk, voice operated switch, or hot mike modes, and muting of transmit and receive for simulation of air-to-ground voice. In addition, this equipment provides for the generation of tones for caution and warning, and the insertion of these tones onto the voice loop. The communication modes and tones are computer-controlled events. Student Station 2 provides for headset operations in push-to-talk mode only.

CREW SOFTWARE TRAINER (CST)

The CST consists of two student stations designated CST 1 and 2. Each of these stations is a fabricated wooden frame into which a facsimile of the onboard keyboard and a CRT have been installed in proper orientation. The CST provides a subset of the components in the SST student station for the purposes of training students in the Shuttle display system; specifically, the student keyboard for display retrieval and modification. Crew software trainer student stations are located separately from the Orbiter system student stations.

SST SOFTWARE DESIGN

Software in the SST computers operates under the control of the SEL-supplied real-time monitor operating system. Executive control is provided by the Crew Training and Procedures Division (CTPD)-developed Simulation Executive Program (SIMEX). The program alternately passes control to the applications modules for each station complex. Each station's application program is allocated 50 msec for processing each time slot, thereby giving each station a basic computation rate of 10 cycles per second. The applications program, together with SIMEX, operates in the SEL 32/77. Concurrently, I/O processing is being performed by the CTPD-developed interactive communications processor running under a modified SIMEX in the 32/55. Figure 5 is a block diagram of the SST software.

Basic to the design of the SST software is the concept of DATAPOOL. DATAPOOL is a unique kind of global common area in memory which can be accessed by many programs using symbolic names to identify specific storage cells. DATAPOOL provides a wider range of structuring flexibility than standard global common in that only the symbolic names used by the program need be referenced in the DATAPOOL common statement. Also, symbolic references to the DATAPOOL may be entirely independent of the actual positioning of data within the memory area.

DATAPOOL resides in shared core and is accessed, asynchronously by both station applications programs and by the ICP. The applications modules take latest available arguments from DATAPOOL and process these data each computation cycle. Results are placed back into DATAPOOL.

Operating asynchronously in the opposite computer, ICP polls station switches, and accepts inputs from student and instructor keyboards. These inputs are processed and placed in DATAPOOL. Output data are taken from DATAPOOL and formatted for output to CRT displays, analog meters, event lamps, alarms, etc.

It was always intended to do asynchronous applications and I/O processing, and the DATAPOOL concept fits that end quite nicely. This concept returned an unexpected dividend. The original intent was for the SST to use only one computer and the initial delivery was on a single processor. The decision to augment the system with a second central processing unit was made, and effort was set in motion to modify the software for dual computer configuration. The DATAPOOL concept simplified this conversion task. Minor modifications were made to SIMEX, a new system generation and compilation was done, and the system was up and running in dual mode. Neither the applications programs nor the ICP required modification.

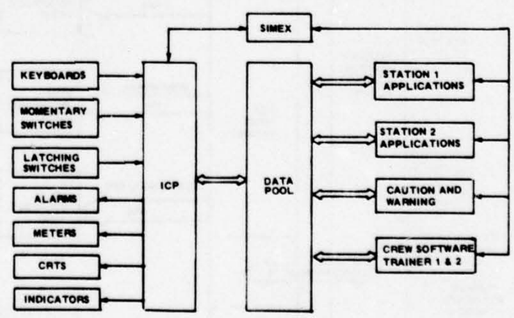

Figure 5 - SST Software System Block Diagram

The programs continued to interact, despite the fact that they resided in separate computers.

One of the SST requirements was that certain parameters be monitored and alarms set if these parameters exceeded certain limits. Rather than have each applications program do limited sense testing, a single program monitor specified parameters at

the system level. Parameter identification, limit information and response directions were to be provided in tables set up when a given applications module was initialized. Again DATAPOOL was used to communicate between the Caution and Warning (C&W) program and the applications modules. When the system was split for dual configuration, C&W was moved without modification. It runs in the same processor with ICP.

Another SST requirement was for instructor entry of malfunctions. These malfunctions generally fall into two categories: logical only, or logical with an associated value. An example of a logical malfunction might be the failure of a fan motor. A line leak with an associated leak rate would be typical of a logical malfunction with an associated value. In the interest of program symmetry, applications programs always process malfunctions. The malfunction is effective only when non-zero biases are combined with the data, and/or true logicals applied to the algorithms. Once again DATAPOOL was used to simplify this task. DATAPOOL variables were created which were always a part of module calculations. The ICP accepted instructor inputs and caused the DATAPOOL locations to activate or deactivate the malfunction.

Finally, the DATAPOOL concept greatly simplified integration of the various applications programs with SIMEX and the ICP. It is not necessary for applications programmers to worry about linkages, calling sequences, etc. Arguments are in DATAPOOL; results go to DATAPOOL. The concept of DATAPOOL is certainly not unique to the SST, but in this case the concept has worked extremely well, and is quite probably responsible for wide student and instructor acceptance.

CONCLUSION

Computer based part-task training systems can provide effective system operations training as an intermediate step between the classroom and full-task simulators. Training systems like the SST can reduce the full-task simulator training load and facilitate more effective use of the available simulator training time by training students in system operation and malfunction procedures.

By establishing a close working relationship between the development engineers and the system instructors, training requirements can be accurately met and misinterpretations and misunderstandings significantly reduced during the development process. Additionally, discrepancies can be more readily identified and resolved by the engineer/instructor team. The end result has been a system delivered on schedule with few discrepancies, which is on target with training objectives.

By presenting complex systems on a single system basis, student concentration and learning efficiency is increased. The instructor/student relationship is strengthened by the one-on-one training leading to continued dialog between the student and instructor as the student progresses through the training program. The necessary student throughput can be achieved by using multiple student stations. Cost savings can be realized using medium cockpit fidelity.

The SST is a success. Students and instructors ask for more of the same. To that end, the SST is currently undergoing expansion to accommodate additional Orbiter systems, and development work is in progress to expand the SST for Spacelab.

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TRIDENT COMMAND CONTROL SYSTEM ONBOARD TRAINING: SIMULATE OR STIMULATE

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This study was conducted under contract with the Naval Underwater Systems Center

INTRODUCTION

Onboard training has probably been a feature of shipboard operations as long as there have been ships. Military vessels are typically in a training mode during peacetime. Fleet Ballistic Missile (FBM) submarines have been somewhat of an exception. This strategic deterrent deploys and operates under secure and alerted conditions. Nevertheless, the FBM platform is used customarily for training junior officers and seamen in the basics of FBM operation, middle-grade officers and enlisted men in supervision and command. Team and ship training exercises are used to practice and verify ship control, emergency and missile launch procedures.

A Command and Control System (CCS) level onboard training system is postulated not to supplant existing training but to complement and amplify it. At this early stage of electronic training device development for onboard application, some positions in the ship's complement are very difficult to integrate into an onboard training plan. For example, the Commanding Officer and his Executive are required to know the functions and capability of all onboard equipment. In addition to this encyclopedic comprehension, they are expected to grasp and be able to execute the skills of wartime and peacetime command--peace with the incumbent problems of limited resources and morale in an austere environment, yet war because of the FBM's deterrent position. A commander must further be prepared both to engage in and to counter the unexpected with penetrating comprehension, planning, perseverance and energy (Andrews & Woods, 1978). The CCS-level trainer is only viewed as an adjunct, with some unique opportunities for learning, to an entire career plan, including diverse sea, shore and school assignments, dedicated to developing this ability.

The primary advantages of onboard training are accessibility, fidelity, cost and recency. Given such onboard training capability, each TRIDENT submarine becomes, additionally, a training station, accessible to all crew members when they are available. The training environment within and surrounding the ship is the operating environment, enhancing the fidelity of training problems. The cost of training aboard is substantially below shorebased training both because the operational equipment serves as training equipment and because onboard "students" occupy a performing billet instead of a trainee billet at the same cost. Finally, recently the time between training and actual performance, is improved in the onboard case both because of the location and because of the much greater trainee availability.

THE PROBLEM

The basic form for the Command and Control system-level function, as discussed in Rizy (1977), is sensor input, command analysis and order generation, ship control and/or defensive weapons response. The sensors are most typically sonar for submerged transit and patrol but also include radar, periscope, monitoring subsystem, magnetic silencing (eventually) and exterior communications. The basic sensor process is defined in Figure 1a.

Two different approaches have been proposed for initiating the CCS process by generating sensor input: simulation and stimulation. Simulation (Figure 1c) reproduces the entire sensor process by use of mathematical models and algorithms. The sensor process is defined as the environment (targets, artifacts, media effects, and own ship influences and signals), the sensor itself (transducers or staves and preamplifiers) and the processing component (cabling, amplification, filtering, beamforming and shading, signal processing and input to the display process). In the case of TRIDENT, the display process is partly accomplished in the AN/UYK-7 computer and partly in the sensor console (Control Display Console in the case of sonar, Standard Information Display for the other sensing subsystems.) Simulation, then, reproduces the sensor data stream and inputs it to the display processor, the UYK-7, for delivery to the sensor operator station. The sensor operator starts the flow of information into the CCS; he also

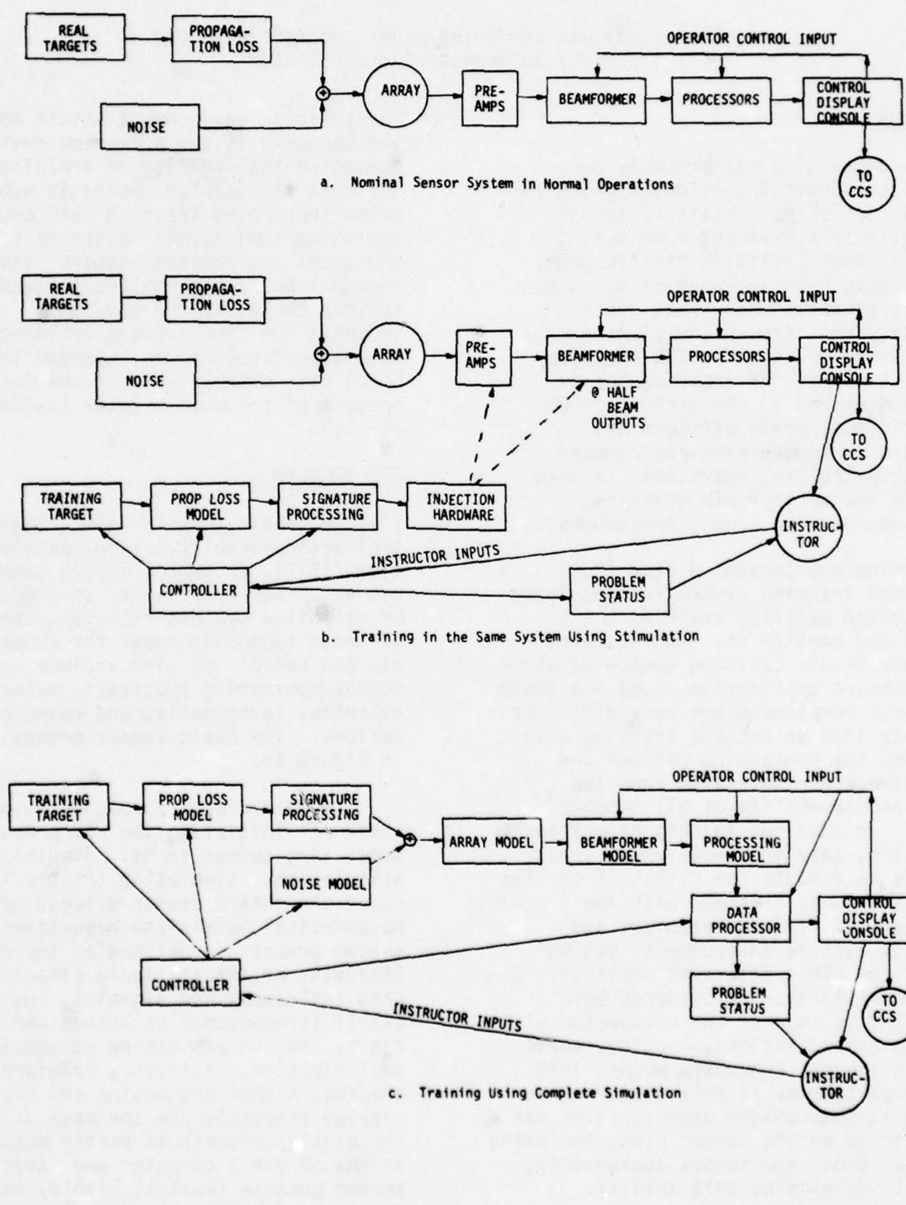

Figure 1. System Functional Block Diagrams

initiates control orders into his console, then into the UYK-7, and, in some cases, back to the simulation program where sensor and processing parameters are changed.

The stimulation approach (Figure 1b) simulates only the target as it would be output by the transducers. Using inverse beamforming techniques, a stimulation system injects the target data, properly timed, into the sensor just after the transducers. The precise injection point depends upon the complexity of the system. In the case of sonar it has been either the beamformer half-beam outputs, the preamplifiers or the staves. (Optional paths are shown as dotted lines in Figure 1b). In this fashion, the stimulation approach is able to utilize the rest of the sensor system, gaining in fidelity and flexibility at the sacrifice of front end simplicity.

THE TRAINING PROCESS

The quality of human performance, whether involving tasks as simple as assembly line work or as complex as command decisions in a tactical engagement, is fundamentally a result of training--or, from the performer's view, learning and experience. Learning has been defined in general as certain relatively permanent changes in behavior as a result of practice (Kimble, 1961). Of chief importance for training and trainer design are the primary determinants of learning: how the learning process works and how it can be facilitated, or at least not hampered, by the training system design. These primary determinants of learning are:

- reinforcement (reward or punishment)
- knowledge of results (feedback)
- motivation
- repetition
- psychological set (orientation, expectancy)
- difficulty of task
- number and strength of possible responses.

Reinforcement may be either extrinsic or intrinsic such as satisfaction or pride in accomplishment. The extrinsic type of reinforcement is not usually needed with adults; reliance on intrinsic reinforcement and motivation is generally identified as "professionalism." In the defense environment, reinforcements and motivation are obviously tied to the survival value of successful performance and its contribution to conduct of the mission.

Knowledge of results is more complicated. When relatively simple tasks are involved, feedback supplied externally by an observer generally has a significant effect on learning. Just the results of complex functions involving many variables and random processes do not contain sufficient information for diagnosis of difficulty, permitting correction and improvement. Anderson suggested that long-term performance trends were more effective. Typical man-machine system training, however, emphasizes analysis of the task to isolate faulty performance, followed by instruction in the specific subtask, drill on the subtask, and gradual integration with the overall task.

Repetition (practice or drill) is another powerful determiner of learning. Although exceptions can be cited where sudden insight leads to mastery, the usual psychomotor, cognitive and perceptual skills exercised in military operations require substantial repetition to achieve and to maintain competence. Repetition has been tied to performance in such diverse fields as SOSUS analysis, photo-interpretation, and medical surgery. In the case of team training such as envisioned here, a single run through of a complex exercise may require days to achieve the proper environment and hours to set up, conduct and evaluate the problem. The need for nearly exact repetition and for variation imposes conflicting requirements on the nature of the onboard trainer and the basic method chosen.

The psychological set or orientation of the trainees can be decisive in forming the results of training. The orientation is determined in part by the sophistication of the training equipment, methods and training personnel and also by the attitude of command. Exercises performed primarily to satisfy some externally imposed requirement or using an inadequate simulation technique are not relevant to the trainees' interests. At best, the results and their consequences do not affect the trainees at all.

The degree of task difficulty determines the rate of learning. Although the trend in systems design has been to try to simplify every task or automate it, many critical and difficult tasks remain for capable and well-trained individuals to do in the TRIDENT CCS. Past team trainers have made the error of simulating the sensor team input and making it infallible. Making a correct decision when all the information is available is trivial. The CCS task is to make the correct decision given incomplete or conflicting information. Even a cursory analysis of the command function at work in avoidance, evasion or attack uncovers the demands made on the function by incomplete, infrequent and inaccurate sensor reporting. Part of the command function is to feedback to the

sensor interpreter, to order adjustments in reporting rate and quality, to check errors and inconsistencies. Hence, the simplifications of previous trainers in combat team training have unintentionally eliminated essential elements of the problems, making the command task far easier than it should have been, and vitiating the value of training.

Finally, learning efficiency is a function of number and strength of possible responses. In laboratory learning studies of the academic type, the experimenter determines the "correct" response, then adjusts the reinforcements or feedbacks so as to strengthen this response and weaken all others. In the TRIDENT-CCS environment, given typical mission-significant problems, the correct responses may not be obvious. A substantial amount of first-rate tactical analysis will be required in many cases to determine the most "correct" or optimal response, the "less correct" and the definitely "wrong" responses.

An additional complication in team training is that responses serve as stimuli for the responses of others. For proper evaluation and feedback, adequate record generation must be provided to trace these sequences back to errors when they occur. Only in this way can the errors be identified and corrected and the consequences of errors made an explicit teaching tool.

The determinants of learning discussed above have provided the basis for postulating certain basic trainer requirements. These requirements will be stated and discussed below. Also, they will be applied to the onboard TRIDENT situation to identify criteria for the subject tradeoff.

TRAINER REQUIREMENTS

Four fundamental requirements are postulated for trainers in general (Smode, 1971) and for the trainer of interest here. These are fidelity of input, flexibility of content, situational control and procedural efficiency.

Fidelity. A strong case can be made for as high fidelity as affordable, both in sensor input and in trainee procedures, actions and consequences. Poor fidelity sonar and radar targets (below classification quality in the case of sonar) do not really train the console operator in the critical and demanding tasks, specifically, the recognition of a target's identity and derivation of its location and motion at low-target levels in noise. Given poor fidelity here, we are back at the level of previous team trainers where command decision-makers are given faulty input and the whole CCS process is inadequately exercised. (The inadequacy cannot be specified in advance; the problem may be too demanding or not demanding enough; all we know is that the problem becomes unrealistic).

Noticeably (to the trainee) less-than-perfect simulation fidelity affects the trainees' motivation as well as contaminates the task difficulty and knowledge of results. The sensor operator is knowingly learning to recognize "fake" signals. At best, the training situation becomes one of "transfer of training" where skills acquired in an artificial training situation will to some degree apply in a future, real operation; the trainee will perform better than if he had never been trained. However, if the sensor trainees are sufficiently demotivated by the artificiality of, for example, calling a 1000 Hz tone a Delta II class submarine, the lack of effort or even hostile attitude toward the training concept is communicated throughout the CCS team. Sensor fidelity is absolutely essential to CCS training.

Operational procedural fidelity is a somewhat different matter. Scenarios can easily be created leading to possibly either the TRIDENT compromising its covertness, losing or impairing external communications, or engaging in maneuvers beyond its safe capability. As discussed in Rizy (1977), a safety watch informed of the exercise is mandatory. Further, some limit must be placed on exercises and their consequences. Those exercises involving risk to security or safety must be reserved for the shore environment. With these safeguards, the CCS trainee should be directed and encouraged to act and respond as operationally proper, and not "in a training mode"--again, to minimize the transfer problem.

Flexibility. A flexible training system should sample the spectrum of situations and demands envisioned for the TRIDENT force. Ideally, this spectrum should encompass types and numbers of threats, onboard marginalities and failures, environmental variations, and all combinations of personnel for each watch of the ship. Certainly, any changes in ship systems should result in, at most, affordable changes in the training system.

Further, the number of variations in a problem should be large enough to make the problem essentially unpredictable by the trainee. This requirement is suggested to avoid the objections raised against PME-tape (Performance Measurement Equipment) driven training used a decade or more ago on surface

ships and subs. Good tapes were difficult to generate; hence, few in number. As a result, they were easy to learn; performance became unrealistically good.

Situational Control. Control of the training situation is vital both from the standpoint of effective training and for ship safety. With respect to training, situational control enables both accurate diagnosis and repetition of the same problem for practice until it is mastered. Given control for repetition, it is easy to postulate modifications to the problem to increase or decrease the difficulty level in order to adapt the problem to the trainees' abilities.

From the standpoint of ship safety, situational control must be considered from three aspects. First, the training operation should cause no compromise of ship safety or security, as by the inadvertant broadcast of signals or by the allowance of hazardous maneuvers, as previously cited. Second, control of the training situation should not weaken the ship's normal surveillance capability. Real potential threats still exist and must be avoided. Third, situational control should dictate that, in the event a hazard is detected, near instantaneous restoration of full operational capability must be provided.

Efficiency. The primary mission of TRIDENT is deterrence, not training. In this context, the time, people and resources dedicated to training must be limited by requirements of the main mission. (It is obvious that suitable training enhances performance of that mission).

The lack of experts and facilities onboard has been addressed in SOTAP (Sonar Operational Training and Assessment Program) in a uniquely effective way. The NUSC/New London personnel and Eclectech, Inc., a consultant firm, have produced an Exercise Controller's Guide which provides aids to brief, setup, conduct, score and diagnose results for many different exercises. Although refinements are warranted in the procedures, the approach, together with the AN/BQR-T4 sonar training unit, have been successfully sea-tested and approved. Thus, it can be concluded that high-quality training can be conducted on site without training specialists, given a satisfactory training system and the quantity and quality of shorebased preanalysis and support invested in SOTAP.

Such programs are still in their infancy. How much training is enough, how long the skills are retained, what is a satisfactory skill level--these questions await experience. Nevertheless, efficiency is a necessary design objective, and in large measure it has been demonstrated.

STIMULATION

The stimulation technique is a special case of simulation where only the received target energy is synthesized and injected into the regular operating sensor system.

The stimulation technique 1) generates the target replica; 2) reformats it as a set of time-delayed signals via inverse beamforming and then 3) adds this signal set to the normal signal flow as close to the outside world as possible (preamplifiers or staves, depending upon the system). The sensor system proceeds normally; digitizing, filtering, beamforming and amplifying the real signals in noise mixed with the injected target signal. The target is then delivered, imbedded in the "real world," to the operator's displays. Here the operator/trainee can manipulate the target's beam, channel or address as any other input. The major stimulation effort to date has been dedicated to onboard FBM sonar training (the AN/BQR-T4) and to shorebased FBM Sonar/CCS team training (Shorebased Operational Trainer component of the 21A37), both in the passive mode.

Applications of stimulation to other sensors and other modes of sonar is conceptually unexplored for the onboard situation. For active sonar training underway on a submarine, it is usually not desireable to actually transmit into the medium. It may be feasible to synthesize the volume, bottom and surface reverberations, plus targets, perform one conglomerate inverse beamform transformation and inject the signal into the system. Stimulation could be applied optically to the periscope system by inserting videotape or computer graphic imagery, such as navigation markers, aircraft or surface vessels, just prior to the exit pupil eyepiece. Periscope training of this sort is well within the state of art, considering recent advances made by General Electric, McDonnell-Douglas and others in the much larger field-of-view flight simulators.

Stimulation for TRIDENT onboard radar training is likewise feasible but does not appear as attractive. Compared to the sonar passive broadband signals and the rich tonal and dynamic variety of sonar target signatures, the radar target for radars currently carried onboard submarines is simplistic; elaborate efforts at fidelity are not deemed necessary. Second, radar is not a primary, long-term surveillance tool. When it is operating, it reveals the TRIDENT's locations to surface, near-surface, airborne and

even spaceborne receivers. The great savings offered by stimulation, injecting targets into real ongoing system processing, is not appropriate here. When radar is on, it's not for training.

Stimulation techniques may be considered for the accelerometer and hydrophone inputs to train operators of the Monitoring Subsystem (MS). The criteria used to reject radar are also appropriate for selecting the MS. That is, the system is always on, passive, and with complex signal characteristics. The intent of MS stimulation would be to train the operator to recognize an impending degradation or fault or an ongoing noise condition without the actual event taking place.

Stimulation has four advantages over simulation for onboard training: fidelity, adaptability, economy and concurrency. The following paragraphs detail these advantages.

Fidelity. Injected signals are relatively more "primitive" in that they simulate far fewer effects than the simulation approach. The non-linear processing, thresholding, integration and scaling inherent in the real sensor system is still operative using stimulation and does not have to be mimicked. Additionally, the real background is typically used with the numerous medium and environmental phenomena furnished "free." As a consequence, with the same resources, target fidelity will be higher using stimulation. This fidelity advantage has been historically true, if one compares the simulated targets used in all previous generations of surface team trainers (14A series), surface sonar station trainers (14E series), submarine team trainers (21A series) and submarine sonar watch trainers (21B series) with the stimulation approach used in the DS-1200 circa 1973. It appears currently the case even for shore-based trainers.

A fair, objective evaluation in this area is difficult for two reasons. First, both simulation and stimulation have been evolving as technologies mature and as inputs from the intelligence community have increased. Second, target fidelity has both frequency and temporal characteristics in the visual and auditory domains. The result is somewhat untractable from a physical analysis viewpoint. A psychophysical or perceptual comparison of simulation with stimulation under controlled conditions has not been reported.

Other than comments by instructors and Sonar Technicians, evidence regarding relative and absolute fidelity is meagre. Onboard simulation deficiencies were identified in an early version of the Q-5 trainer (CNO letter, 1975) but not specifically detailed. The shorebased simulation still lacks auditory output, an essential element of training (IBM, 1978). The current comparative state-of-art may be readily compared at the Submarine School, New London, when the SOT stimulation system is in place next to the 21B64.

All that can be posited with respect to fidelity is the present situation. Stimulation techniques have demonstrated realistic targets, visually and aurally, broadband and narrowband passive, to trained Navy sonar instructors from the U. S. Submarine School, New London. Simulation has not been as successful.

Adaptability. The stimulation approach is relatively immune to improvements in either the hardware or the software characterizing the tactical system. New system designs have no effect on stimulator hardware or software. The only changes in the system that would affect stimulation are those upstream of the injection point: transducers, baffling and the sonar dome.

The Naval Training Equipment Center (NTEC) has traditionally favored simulation, but found in the case of the AN/SQS-26 Surface Sonar that simulation, which has traditionally lagged the real system by a year or more, could not keep up with system changes. Further, simulation has rarely produced a satisfactory aural signal. The 21B64 trainer mentioned previously has no aural capability; to supply it, an additional system must be added that will constitute essentially a parallel stimulation system. As a consequence of these types of difficulties in achieving and maintaining fidelity in the face of continued system modifications, NTEC has specified stimulation for its two most recent shorebased classification-level sonar trainers, the Multi-Environment Trainer (MET) being built for the Saudi Arabian Navy and the 14E28 ASW Team Trainer for the FFG-7 Patrol Frigate.

Economy. The stimulation approach costs less in a shipboard setting than simulation for two reasons. First, as mentioned above, the modelling effort is considerably reduced, being limited to the target energy as influenced by medium and hydrophone effects, in contrast to the full simulation approach, encompassing the rest of the processing chain. The second reason is that the instrumentation required to implement the trainer is consequently smaller. The tactical hardware, a driving cost in shorebased trainers, is already onboard. The software needed for training implementation and control is negli-

gible compared to the simulation approach.

By way of illustration, the AN/BQR-T4 Onboard Sonar Trainer uses two National Semiconductor Model IMP-16C microprocessors, one for signature processing and the second for inverse beamformer control, geometry and problem control, and propagation loss computation. The core requirement is 4.5K 16-bit words for a single target, simple propagation, three-array signature processing and shaping, and injection. An early version of the AN/BQQ-5 tactical onboard trainer (IBM, 1974) used a 30K 32-bit word program for a single target, own-ship geometry, passive and active sonar.

The shorebased 21B64 simulator uses two AN/UYK-7s with a peak processing time of 95.6 percent and a program of 155.2K 32-bit words. The memory loadings are: core, 86 percent; disk, 80 percent; and CDC drum, 43 percent.

Concurrency. The typical and probably necessary manner in which simulation has been used in shipboard applications (e.g., the AN/BQQ-5 OBT) is to simulate the entire problem; that is, to remove the console from an operational mode, load a training problem in the driving computer, and run the training exercise isolated from real world data. (As will be seen later, complete simulation does offer significant training advantages.) Restoration to normal operations requires deleting the training program, loading the operational program and restarting procedures, presently a 15-minute operation in the AN/BQQ-5 case. Stimulation, however, in its typical application of injection into sea noise, leaves the normal operating programs alone. An instructor has complete control of the target from a control panel and, with any of a number of actions, can remove the target from a critical location or terminate the exercise.

This feature of stimulation has two advantages. First, the operator/trainee monitors the real environment and in the alerted search for the training target may just as well detect a real target. Second, and absolutely critical from the viewpoint of CCS-level training, no portion of the CCS operational system is off-line. A sudden emergency, tactical incident or receipt of a critical message, a call to General Quarters would not require a system reload. Even during training, the CCS stands ready.

Certainly, the simulation approach could involve merely the injection of a synthesized target into the sensor data resident in the display processor. In this sense, the CCS system, working against simulated targets in real noise, could enjoy the advantage of concurrency. The detailed implementation of this approach is presently under development for the BQQ-5. A preliminary analysis indicates that simulation would be very complicated when mixed with operating programs. Consider that operator control inputs affecting target appearance (such as change in filter band, processing time or beam) would have to be fed both to the operating system and to the target processing models simultaneously, producing parallel changes in the real noise and simulated target. The BQQ-5 simulation/injection technique will still require substantial software to model the target and will still pose a concurrence problem.

SIMULATION

The simulation technique is mathematical modeling of all system components with the exception of some display processing. In the case of TRIDENT, the technique would involve a simulation program resident in one of the AN/UYK-7 computers generating, typically, the area of the medium as seen by the sensor, targets and their dynamics, environmental effects, plus sensor, array and baffle effects, beamforming, filtering, spatial or temporal averaging or differencing. Again, typically but not necessarily, the sensor operator station would be taken off-line from normal operations into a training mode. The station(s) would output target data and other control orders to other trainee stations used for target analysis, tactical decision making and response.

The typical implementation described is applicable to any sensor, including periscope and radar. Since it simulates the entire environment, it does not require that the actual operational system be deployed; hence, simulation is particularly appropriate to periscope and radar training where deployment might compromise TRIDENT covertness.

The advantages of this approach include front-end simplicity, greater situational control, and ease of multi-target exercises. These advantages are elaborated in the next sections.

Front-End Simplicity. The entire sensor system up to the display processor is untouched by simulation, eliminating the need for special interfaces and protection circuits. This advantage is more than outweighed, however, by the additional burden placed on the Data Processing Subsystem which is already loaded by operational demands. Addition of training programs may be possible without modification or deletion of operational software. Concurrency and speed of restorability will be sacrificed unless

simulated targets are added to the normal processing, in which case operational programs would probably have to be modified. Even in this case, the additional training software may cause a concurrency problem because the Data Processing Subsystem is already loaded heavily.

Training Situation Control. Since processing of real data is not done in the usual implementation of simulation, the entire signal/noise domain is under program control. This feature enables precise repetition to drill individual trainees and to permit precise comparisons (with the exact problem) among different watches or crews. Since such training is not tied to real ship maneuvers or background noise, realistic training could be provided at dockside; patrol training could be provided during transit; and familiarization with future operational areas could be provided. Finally, replay of a problem for stop-motion analysis and instruction is easily accomplished.

Stimulation can be adapted to match some of these features. For example, replay of a problem, different noise or ship maneuvers can be supplied through use of a PME-type recorder with the trainee station(s) off-line. One of the objectives of the AN/BQR-T4 Exercise Controller's Guide and of the governing SOTAP is to provide standardized problems and procedures in defineable (and roughly equatable) environments either for drill or for operational readiness-type testing. The SOTAP has been at least partially verified at this date.

Multi-target Capability. Once the ocean environment and a single target have been faithfully simulated, the number of additional targets, artifacts and decoys available should be limited only by computer capacity. In practice, this is presently a problem. Simulation of the ocean and a single target already overloads a dual-bay UYK-7 in the 21B64 trainer. In the future, savings should be effected,but hopefully not at the expense of fidelity. Also, because of the non-linear character of sonar processing, targets are not merely additive, simply superimposed. Rather, targets do interact such that one suppresses the other--an involved modeling problem. As discussed earlier, this enhanced capability is a two-edged sword. Very busy scenarios pose problems not only for trainees but for evaluation and for ship safety.

RECOMMENDATION

The primary conclusion of this study is that onboard stimulation rather than simulation should be employed to drive all sensors but radar and periscope in order to train the Command and Control System team. This conclusion is based upon stimulation's proven superiority in

- sonar target fidelity
- adaptability to operational system modifications
- concurrency with operational capability
- economy in implementation, utilizing resources at hand
- simplicity of operation.

Simulation is not without merit, however. It is advantageous in providing situational control for practice or analysis of replay, and possibly the capability for multi-target problems, although the value of this capability has been questioned by NUSC/NLL in the onboard setting.

Neither technology is fully mature. Both have their problems in the onboard environment. Either could provide the absolutely necessary onboard complement to controlled, shorebased training. The weight of evidence to date, however, is that training via stimulation will train better, safer and more economically than simulation in the foreseeable future.

REFERENCES

Anderson, N. H. Paper presented at "Applications of Decision and Information Processing Research to the Design of Command Control Systems Workshop." Naval Postgraduate School, Monterey, California, October 4-6, 1971. Prof. Anderson at University of California, San Diego.

Andrews, F., and Woods, C. E. Surprise in naval warfare. In Proc. U. S. Naval Institute, 104(5), May 1978, 84-97.

CNO Letter, AN/BQQ-5 Sonar System Onboard Training Capability. File number 224F/101385, 3 June 1975, with references to PCO USS Los Angeles (SSN 688) letter 3500, serial C19-74, 9 December 1974, and COMOPTEVFOR letter, Preliminary Assessment of AN/BQQ-5 Sonar System Training Mode, serial C326 of 9 December 1974.

IBM Report, AN/BQQ-5 Tactical/Test Program Description. Sonar Software Development Document 6934813, Manassas, Va., April 1974.

IBM Report, Submarine Ocean Acoustic Operator Trainer Device 21B64A: Computer Program Performance Specification (U). IBM CD No. 2835491, 31 May 1978. CONFIDENTIAL

Kimble, G. (Ed) Conditioning and learning. 2nd edition. New York: Appleton-Century-Crofts, 1961.

Muller, P. F., Jr., Sidorsky, R. C., Slivinski, A. J., Alluisi, E. A., and Fitts, P. M. The symbolic coding of information in cathode ray tubes and similar displays. USAF, WADC Technical Report 55-375, October 1955.

Rizy, E. F. Trident Command and Control System Onboard Training/LBEF Development Concept Demonstration. Raytheon Technical Report prepared for Naval Underwater Systems Center, Newport Laboratory, Rhode Island, October 1977.

Smode, A. F. Human factors inputs to the training device design process. Dunlap and Associates Technical Report prepared for Naval Training Device Center, Orlando, Florida, September 1971. AD734644.

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A DYNAMIC SIMULATOR FOR TRAINING WITH MAN-PORTABLE AIR DEFENSE WEAPONS

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and
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INTRODUCTION

The depth of training required for weapon systems that have a high man-engagement performance requirement is a difficult task.

Should a man solely depended upon to engage and destroy a high-performance/high-value threat be allowed to train by actually firing the weapon? When the gunners number in the thousands and the weapon costs in the thousands, would this be practical? Conversely, can the gunner realistically be totally trained without experiencing a live weapon firing? Even the USA and USMC differ in their solutions to this dilemma as evidenced by their individual approaches to training for the Redeye weapon. Hopefully, both services will realize that for the new Stinger weapon the common goal must be a well-trained, confident gunner.

Both the Redeye man-portable air defense weapon and its upgraded version, designated Stinger, are designed so that one man can shoulder-launch the missile to intercept and destroy threats ranging from hovering helicopters to high-speed maneuvering jet aircraft threats.

The necessity for having a well-trained gunner that can engage a high-value threat on the first attempt requires a high degree of weapon confidence and operational proficiency. Brunswick Corporation as the prime contractor for the USMC to develop a Redeye Launch Simulator (RELS) and a Stinger Launch Simulator (STLS) believes the answer lies in providing a trainer that allows a cost-effective live firing experience. This training of a new student or requalification of a trained gunner can be effectively culminated by firing a low-cost duplication of the actual weapon.

TRAINING NEED

The Stinger Weapon System's introduction into our arsenal of air defense weapons creates a unique training requirement. It is a man-portable air defense weapon that can engage all types of threat aircraft from hovering helicopters to high-speed maneuvering jets. Different than its predecessor, Redeye, the Stinger has an all-aspect engagement capability.

Stinger is an extremely effective weapon in the hands of a well-trained, skilled, and confident gunner. How do we attain this well-trained, skilled and confident gunner? The ideal method would be to provide the gunner with an adequate number of Stingers and allow him to fire at targets representative of the threat until he becomes proficient, and confident in his weapon's capabilities, and of course to provide additional Stingers periodically so he could maintain his proficiency. Once the gunner has attained proficiency and established confidence, he can then concentrate on the other combat skills required to become totally effective.

Mission impossible? Only partly. The Stinger Weapon System costs in excess of $30,000 each and the costs associated with developing and using representative targets are astronomical.

How then can we hope to train a Stinger gunner? Weapons system simulation is the answer, and not just simulation, total gunner related weapons simulation.

The Stinger Launch Simulator (STLS) provides total weapon system simulation due to the requirement that the gunner perform the required prelaunch functions which allows the simulator to function exactly like the Stinger weapon, through the launch of an eject only missile. This provides the gunner with a dynamic simulation of weapon system performance while under pressure of an incoming aircraft as depicted in Figure 1.

Figure 1. STLS Live Firing

Stinger is a fire and forget weapon and so is the STLS. Once the Stinger exits the launch tube the gunners participation in the engagement has ended. STLS takes the gunner through all of the prelaunch steps and launch sensations which are identical to Stinger. The only steps in the Stinger engagement sequence that STLS does not simulate is missile flight and intercept.

The STLS gunner experiences everything he would with the Stinger except for the thrill of the kill. Additionally, he is required to handle the STLS as he would a Stinger in regard to safety. STLS will indeed fill the need for a training device that will build confidence and increase proficiency while keeping training costs low.

SIMULATOR CONCEPT

The STLS concept is based on maximum duplication of weapon design and usage characteristics. Identifying features of the two systems shown in Figures 2 and 3 are difficult to distinguish, yet one is a $30,000 weapon, the other a $350 simulator.

Figure 2. Stinger Weapon

There exists four **major** subsets of the basic simulator including launcher, eject motor, eject missile and support items. Each of these were given special attention in terms of design criteria to maintain maximum representation of the weapon at minimum cost.

LAUNCHER - The launcher is basically an expended Stinger Launcher modified to launch eject missiles on a recurring basis. This entails mounting the IR seeker, normally expended with the weapon, to the launcher allowing extensive reuse. An electronic module is added to the reusable gripstock to provide the interface electronics normally associated with the weapon missile. Additional minor items such as a retainer screw and igniter interface have been changed to permit extended reuse.

Since the standard launch tube is normally expended after each firing, a protective shroud is added to the motor. This allows a minimum of 100 firings before the relatively low cost tube must be replaced. The higher cost-items such as the seeker, gripstock and electronic module are easily added to a new launch tube.

Figure 3. Stinger Launch Simulator

EJECT MOTOR - The eject motor is the heart of the expendable part of the system. Conceptually the approach is to maintain a man rating level of safety while incorporating as many value engineering features as possible. An example is the weight sensitivity of the weapon boost motor forcing use of a high-strength, low-weight 300 Maraging Steel case which is also high cost. With STLS where weight is not critical, an extra thick 4130 steel case is utilized.

Cost reduction designs have also been implemented on the nozzle assembly, propellant retainer cap and eject missile interface hardware. All performance characteristics such as pressure, total impulse, burn time, etc., have been retained so that the launcher eject phase of the flight is identical to the weapon.

EJECT MISSILE - The eject missile consists of the man rated, low-cost eject motor attached to a ballasted forward section. Conceptually the eject missile has a total weight identical to the weapon in order to ensure that the eject parameters remain identical. Low-cost production techniques have resulted in an aluminum extruded section cut to length, threaded and machined at the motor interface and edges chamfered on the front end. When

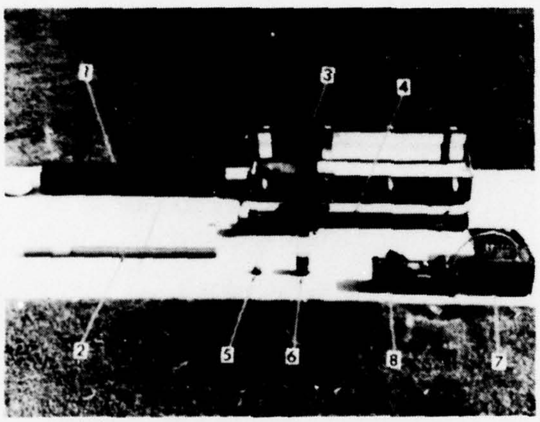
assembled to the motor it is packaged in a missile container allowing ready removal and subsequent simple insertion into the launch tube.

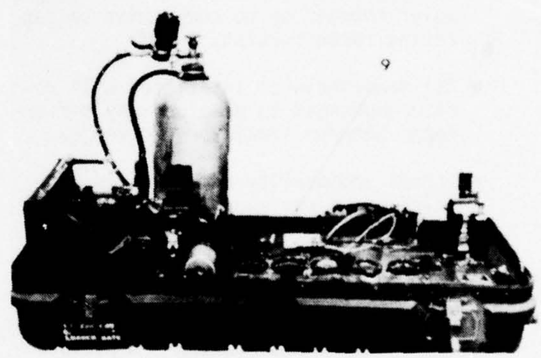
SUPPORT ITEMS - In the earlier RELS development program little attention was placed on support items resulting in significant recurring costs associated with these items. Realizing the potential quantities associated with STLS training, a new approach was taken. Instead of utilizing an expendable tactical Battery Coolant Unit (BCU), a trainer battery coupled with a gas bottle was selected. Launcher design was established such that the bottle could be easily installed just prior to firing. Although initially conceived as a single shot device for simplicity, an option for a multishot gas supply has been developed. Thus the per firing costs for support items can be reduced to the point where the only significant recurring cost is associated with the eject missile.

With the established conceptual approach of maximum weapon duplication at minimum recurring cost, design definition to ensure compliance was initiated. All lessons learned on a predecessor program (RELS) coupled with response to the defined training need were established as design criteria.

DESIGN APPROACH

To ensure full system value, the design approach to the STLS consists of a total training package. The package, including all support items, is shown in Figure 4.





1. Eject Missile Container
2. Eject Missile
3. Launcher Container
4. Launcher
5. Gas Bottle
6. Trainer Battery
7. Battery Charger
8. Battery Charger Receptacle
9. Redeye Test Set Modified for STLS

Figure 4. STLS Training System

In addition to the key criteria of maximum weapon similarity at minimum recurring cost, a number of key design factors were established including:

- Deliver a fully assembled eject missile to minimize handling and safety as related to the trainee.
- Maximize the number of eject missiles in each disposable container yet stay within human engineering limits.
- Package all items except the eject missile in the launcher container so that the required gas supply and battery power are readily available in the quantities needed.
- Ensure the gas bottle design (6000 psi Argon) is safe during shipment as well as if there is a post installation mission abort.
- Perform extensive tests to verify eject motor changes so no compromise to man rating factors exist.
- All man/simulator interfaces will remain unchanged to preclude any differences between simulator and weapon.
- Stress commonality of simulator with existing weapon support equipment.

As illustrated in Figure 4, the design approach for the various subsystems can be highlighted as follows.

1. EJECT MISSILE CONTAINER - A picture of the container with one eject missile partly extended is shown in Figure 5. The container is an off the shelf government approved container that is low cost, readily available and can house up to three eject missiles. Plans are to make the container expendable to preclude logistic problems. Dunnage is provided on the ends and center for support and simple clamped ends are provided for retention. Design considerations utilized human engineering limits.

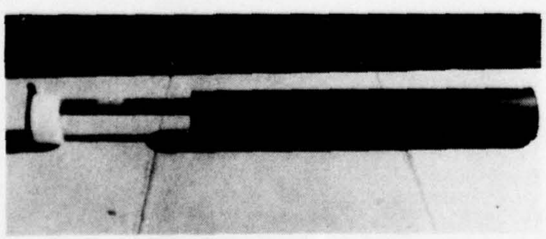


Figure 5. Eject Missile Container

2. EJECT MISSILE - The eject missile is illustrated in Figures 6 and 7 as the forward section and eject motor respectively. Mating of the two units form the assembled eject missile.

The eject missile forward section is a simple aluminum extrusion groved and cut off to provide an identical weight to Stinger. Minimal manhours to finish the forward and aft sections by machine have been included. An alodine coating is applied for long-term exposure protection. A key factor is to maintain a precise alignment between the eject motor and forward section and to minimize costs. It currently is an expendable item, but value engineering studies may determine that reuse is cost-effective.

Figure 6. Forward Section

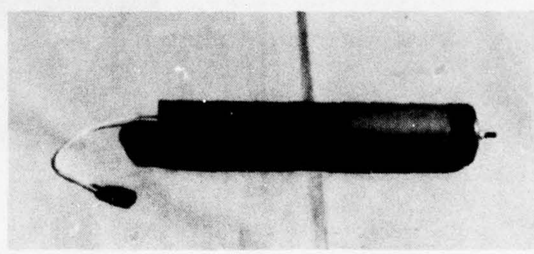


Figure 7. Eject Motor

The eject motor is the key component in the areas of cost and safety. A fine balance must be achieved between low cost and retention of man rated safety levels. A deviation from Stinger was included only in the areas of motor case thickness and material, nozzle design and boost/sustain separation interfaces. No change to the internal combustion chamber design, propellant design or squib design was allowed. A minimal firing test program to verify all changes is in process. In areas of change, high safety factors were established to allow cost-effective design where no weight sensitivity exists. An integral blast shroud was added to the motor to prevent exhaust impingement on the launch tube. This is needed to en-

sure a minimum of 100 firings from each launch tube. Also shown is the squib lead with connector which mates to the launcher. Care to ensure proper EMI protection on heavily instrumented ranges was also considered.

3. LAUNCHER CONTAINER - The launcher container shown in Figure 8 houses the launcher, 3 trainer batteries and 45 gas bottles.

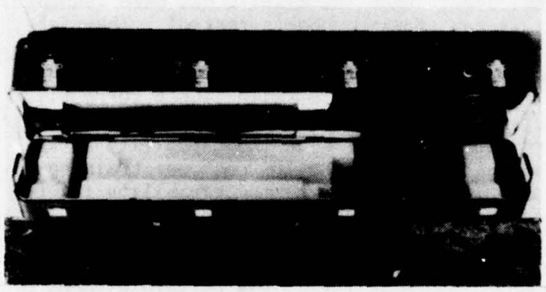


Figure 8. Launcher Container

Modification to the dunnage of the Stinger qualified container is all that is required for this container. Thus all the key launch hardware, except the eject missile, is provided in a single reusable container.

4. LAUNCHER - The modified GFE Stinger launcher with gripstock is shown in Figure 9. Only the forward mounted seeker provides visual identification of differences between a STLS and a Stinger launcher. Additional interface modifications including the electronic module, solenoid valve, coolant passage, gas bottle receptacle, torque screw retainer and connector interface are needed for the system to function but are not evident to the trainee. All modifications are kept from interfering with the gunner's normal handling of Stinger. Thus the changes are either in the forward area, inside the gripstock or behind the gunner's shoulder.

Figure 9. STLS Launcher

To protect overall cost effectiveness, the hardware attached to the launch tube was minimized since it is discarded sometime after 100 launches. The remaining parts can be reused with a new launch tube.

The electronic module, tightly packaged in the gripstock, provides the electronic signals normally associated with the missile. These include a time delay, igniter pulse tailoring, tone cutoff and solenoid valve activation. Printed circuit boards within the module are replaceable items.

5. SUPPORT ITEMS - A number of support items exist which include the gas bottle trainer battery, battery charger and battery charger receptacle.

The gas bottle is the major new designed piece of equipment compared to the previously successful RELS. To allow use of the GFE trainer battery, a source of Argon gas to cool the seeker is required. The ultimate design considered cost, safety and installation human engineering factors. For cost effectiveness, a standard TOW qualified bottle was modified for STLS including safety factors of 2 times MEOP as proof pressure. The volume of 2 in^3 was derived from Stinger data. Remaining to be defined was the bottle to launcher interface which had to include an automatic means of bottle opening, venting considerations and removal problems. The final configuration allows safe installation within human engineering allowable torque limits, noninterference with gunner functions, safety to the gunner and a positive venting system for removal. Drop tests were also performed to ensure handling safety.

The trainer battery charger and receptacle are all GFE items and have proven their usability in previous field training activities. This equipment allows reusability of the battery at the field unit support level.

6. TEST EQUIPMENT - The non-exacting requirements for STLS permitted imagination in defining the test and checkout equipment. Rather than specify a high cost Stinger test set for STLS, Brunswick opted to upgrade the Redeye/RELS test set to be compatible with STLS. Additions for different seeker sensitivity, IFF and gas supply were the prime changes required. These have been successfully completed on the initial unit thereby saving the Stinger training program thousands of dollars. Similar modifications can be performed on additional test sets at approximately 15% of the cost of building a Stinger test set.

TRAINING APPROACH

The Stinger gunner must be capable of engaging and destroying all types of low-altitude aircraft from helicopters to high-performance jets. To accomplish this, the gunner must be highly proficient in numerous mental and physical skills with consistent performance capability. The operational proficiency and consistent performance must be achieved in the Stinger training program. The gunners performance reliability is attained by instilling confidence in his operational abilities and the systems capabilities to intercept and destroy threat aircraft.

The training program for Stinger gunners is similar to the current Redeye training program. This begins with a four-week school at the U.S. Army Air Defense School, Fort Bliss, Texas. The subjects covered include weapons system capabilities, aircraft recognition, range ring profiles, map reading, tactical employment and system trainers. Due to the peculiar mission of Stinger, many hours are devoted to the use of trainers and the Stinger Launch Simulator. The trainers currently being utilized are the Field Handling Trainer (FHT) and the Tracking Head Trainer (THT). The FHT is an expended launcher which has been ballasted to simulate the weight and balance of the tactical weapon. It is used for familiarization and reaction drills and has no functional parts. The THT is a full-size model similar to the actual weapon and provides all functions of the weapon except missile launch. It is used primarily for tracking, target acquisition and ranging.

The Stinger Launch Simulator (STLS) is the link between the trainers and the weapons system. It provides a low-cost, highly representative firing system which simulates all aspects of the Stinger firing through the launch motor firing and ejection of the training round. The STLS provides the means for training and establishing performance proficiency of the Stinger gunners in the handling, operation and firing characteristics of the weapon. The STLS duplicates the Stinger weapon through all operational phases including activation, acquisition, time delays, initial launch characteristics such as launch motor ignition, recoil, over pressures, backblast and weight loss on missile launch. STLS provides complete weapons system simulation with the exception of sustained missile flight and intercept, thereby simulating everything that the gunner has any control over.

The STLS primary role in the training structure is to build confidence. Its secondary role is as a handling and a weapon familiarization trainer. STLS may play an even more important role for the Stinger system than RELS did for Redeye. STLS may be the one firing experience that the gunners will have because of the high cost of Stinger. While all Marine Redeye gunners fired a Redeye upon graduation and an annual required round, this will not be possible with Stinger. Thus one of the most important training experiences, actual weapon firing, is lost. The STLS has been developed to fill the void created by the loss of actual weapon firing. It will provide the Stinger gunner with a simulator that will take him through all of the prefire and fire events that he has any control over. Once the missile has been launched, it is out of the gunner's control. Therefore, to enable the Stinger Missile to hit the target, it is necessary to perform all of the steps leading up to missile launch correctly. Because of the low cost per firing, STLS will provide the gunner with the capability to refine his skills. The low cost per training round will also provide the capability for repeated firings, thus increasing the gunner's abilities. With the enhancement of his abilities comes confidence in himself and in his weapon. Because there is a certain element of fear involved in firing a weapon of this type from the shoulder, repeated firings of the actual weapon or an authentic simulator will alleviate this fear. Also, there is often a problem of handling this type of weapon after training with mockups or inerts. STLS requires the same type of handling as the Stinger weapon thus adding another benefit to its use.

Training for a weapon system such as Stinger should not be taken lightly. It is a system capable of destroying a sophisticated threat or one of our own aircraft. To ensure that the Stinger weapon eliminates the proper threat requires a well-trained confident gunner. STLS provides insurance that a skilled, confident gunner is in the field.

HUMAN FACTORS

The Man-Portable Air Defense Weapon Systems (MANPADS) are unique in that their operational effectiveness is totally dependent on the gunners performance. The individual gunner is responsible for the correct operation of the weapon and required engagement procedures and procedural sequence for specific types of aircraft. The gunner engagement requirements have created physiological and psychological performance standards which were beyond the documented state of the art. The high-performance standards are essential in order to engage and destroy contemporary and future low-flying, high-velocity tactical jet aircraft. The majority of existing low-flying attack aircraft have the capability of velocities from approximately 400 to over 600 knots. These speeds translate to 205 → 308 meters per second that the aircraft is penetrating the defended airspace. Therefore,

the air defense gunner must perform his operations and engagement decisions in a very few seconds.

The engagement procedures are extensive and require rapid decisions and motor skills on the part of the gunner. The major engagement tasks are shown in Figure 10.

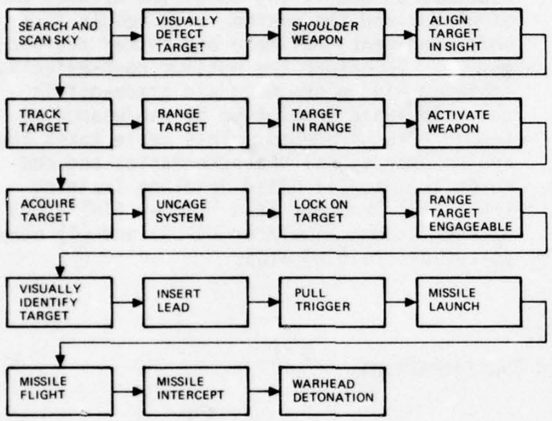


Figure 10. Engagement Procedure

The gunner tasks and control of the missile weapon system culminates with the missile launch. Once the missile is launched the internal navigational onboard system guides the weapon to the target.

The gunners training enables the individual to achieve a high standard of engagement performance. The gunners performance proficiency is continually upgraded, maintained and tested through (simulated) training programs. The one factor that is of major concern and often questioned is the gunners anxiety and reliability to actually fire a 2.75 inch missile from his shoulder. The gunner anxieties are created by the missile launch functions.

GUNNER ANXIETIES

The gunner anxieties are basically a fear of the unknown relative to the missile launch characteristics. The majority of air defense gunners have experienced firing rifles and other small arms prior to entering Redeye or Stinger weapon systems training. During rifle firing the gunner experiences a substantial recoil or "kick" and a high degree of noise. This previous experience conditions the man to be apprehensive about the firing characteristics of larger weapons. In addition, the gunners are exposed to motion picture films of Redeye and Stinger firings and also one actual demonstration firing during training. The actual firing is very impressive and also appears very awesome to the gunner spectators. The firing takes place in front of the spectators with the rear of the weapon pointed toward them. This situation amplifies the missile launch characteristics.

- Missile launch characteristics (spectator perception)

Noise - is amplified as it is directed from the tube toward the spectators
Flash - the motor ignition is a short flash of fire
Recoil - the launch tube appears to jump on the gunners shoulder
Debris - dust seems to surround the gunner
Smoke - appears to envelop the gunner
Launch - missile shoots from launcher on gunners shoulder and the sustainer motor ignites a short distance in front of gunner

The preceeding perceived firing characteristics are not representative of what a gunner actually encounters when firing a weapon from his shoulder.

When the weapon is on the gunners shoulder, he is totally protected from the missile launch characteristics. The noise, overpressures, flash, backblast, smoke and debris are directed behind the gunner. The recoil is approximately the same as firing a .22 caliber hornet rifle. The most noticeable sensation is the change of weight as the missile exits the launch tube. The actual firing characteristics are very stringent relative to the gunner.

- Firing conditions

Noise (at gunners ear) - $\leq$168 db
(25 db ear protection) - $\leq$143 db
Recoil - <0.8 lb/sec
Overpressure - <3.0 lbs per sq in
Backblast - will not impinge on gunner - behind him
Toxic Gases - parts allowable to affect gunner
Smoke - behind gunner
Flash - short duration - behind gunner
Weight transfer - perceived in $\leq$0.3 seconds.

The actual weapon firing conditions are probably less than firing an M-16 rifle. However, only through firing the actual weapon or a highly representative training aid will the gunner anxieties be reduced to produce a reliable performance from an individual in combat.

STINGER LAUNCH SIMULATOR

The firing of a Stinger weapon by every gunner is cost prohibitive. In addition to the cost of a weapon is the target, firing range and range control, safety and ordnance personnel. In order to effectively condition a gunner to firing conditions, a training simulator has been developed.

The first launch simulator was developed for the Redeye weapon system. Biomedical studies disclosed that firing the Redeye Eject Launch Simulator (RELS) induced the same gunner anxieties as firing the weapon. Also, that once a gunner had fired at least on RELS he was significantly more relaxed at the first time he fired an actual weapon. The results of biomedical tests and extensive interviews with gunners substantiated the need for a high fidelity launch simulator for the Stinger weapon system.

The Stinger Launch Simulator (STLS) has been designed to duplicate the Stinger weapon firing conditions. The exact duplication is essential particularly if a gunner does not have the opportunity of firing a weapon prior to a combat situation. The higher fidelity of the firing condition between the simulator and the weapon will result in a more confident, reliable and better trained gunner. To ensure the optimum cost-effective training aid, a training aid trade-off is shown in Table 1 relative to man/weapon performance requirements. This table takes the weapon operational characteristics and compares them to (1) Field Handling Training (FNT), (2) Tracking Head Trainer (THT), (3) Stinger Launch Simulator (STLS) and (4) other potential training aids.

Table 1. Training Aid Considerations

MAN/WEAPON PERFORMANCE	WEAPON	FHT	THT	STLS	OTHER
A. Handling					
Weapon weight <35 lbs	x	x	-		-
Shouldering weapon <4.0 sec	x	x	x	x	x
IFF connection <3.0 sec	x	x	x	x	x
Center of gravity					
Forward of shoulder ≤1.0 inch	x	x	-	x	-
Pursuit tracking					
Pointing error					
Low	x	x	x	x	x
Medium	x	x	x	x	
High	x	x	-	x	-
Portability					
5th percentile man	x	x	x	x	-
95th percentile man	x	x	x	x	x
Overall length	x	x	x	-	-
B. Engagement					
Activate to fire ≤10.0 sec	x	-	x	x	x
Target at launch	x	-	x	x	x
C. Environmental					
High temp (operating) 165°F	x	x	x	x	x
Low temp (operating) -25°F	x	x	-	-	-
D. Firing Conditions					
Noise <168 db	x	-	-	x	?
Recoil <0.8 lb/sec	x	-	-	x	x
Overpressure <3.0 lb per sq in	x	-	-	x	x
Backblast <150 meters	x	-	-	x	x
Toxcity <standards	x	-	-	x	x
Weight transfer ≤22.9 lbs	x	-	-	x	-
Flash min detect.	x	-	-	x	-

UNIVERSAL TRAINER

The STLS promises many product improvements in the future. The main thrust should be to provide a universal trainer, or one trainer that could be a Field Handling Trainer, Tracking Head Trainer, and Stinger Launch Simulator all in one. It could be easily modified to provide any of the following:

1. Field Handling Trainer (FHT) - Insertion of an inert missile to duplicate weight to provide FHT for weapons handling and reaction training (Figure 11).

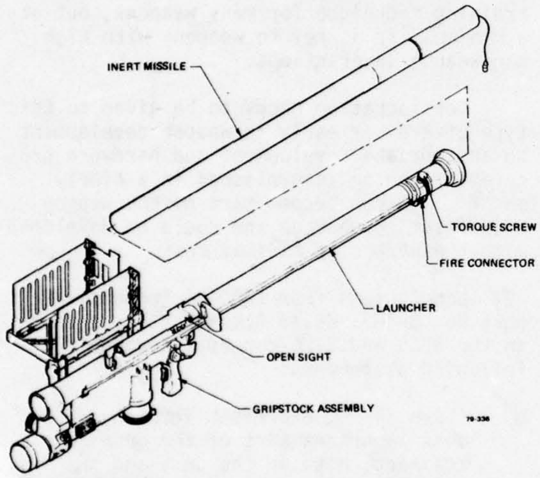


Figure 11. Field Handling Trainer

2. Tracking Head Trainer (THT) - Insertion of inert missile and multishop gas bottle or insertion of an 80 shot gas bottle in launch tube duplicating weight of missile would provide THT for use in MTS (Figures 12 and 13).

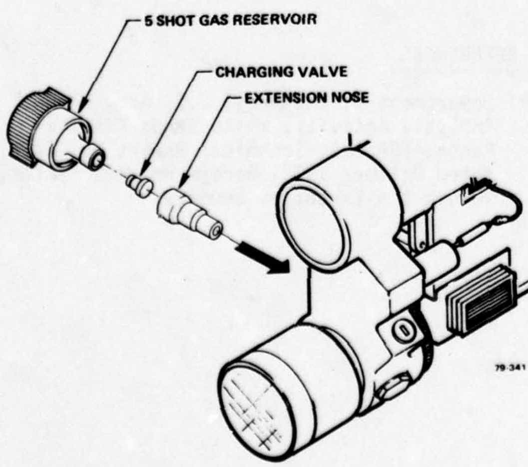


Figure 12. Multishop Gas Bottle

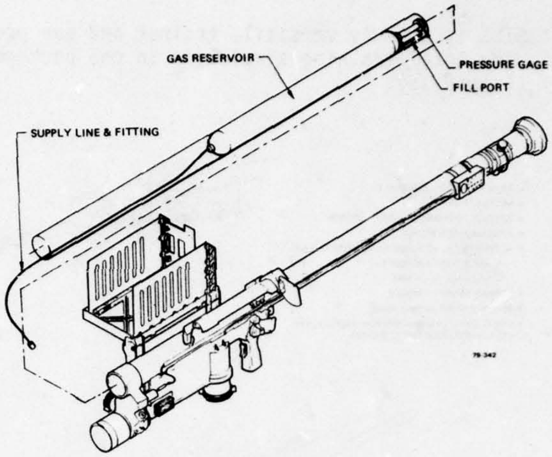


Figure 13. Tracking Head Trainer Multishot STLS Gas Reservoir

3. Performance Indicator - Addition to either STLS or STLS/THT to show gunner performance can be either mounted on launcher, or remote readout with transmitter mounted on launcher (Figure 14).

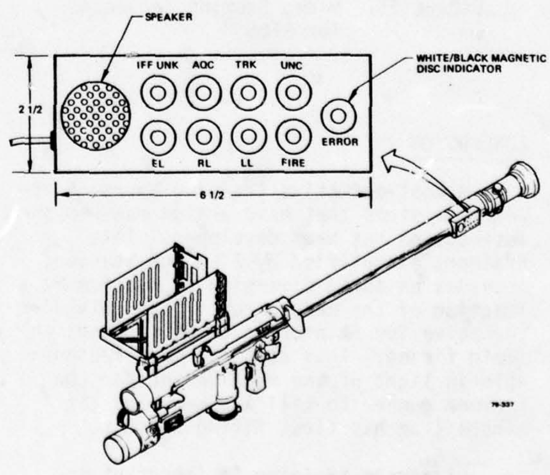


Figure 14. Performance Indicator

4. Optical Scoring Concept

a. 35 MM still camera with telephoto lens and automatic film advance.

b. Modified polaroid camera with special telephoto lens and automatic film eject.

c. Lightweight TV vidicon camera with telephoto lens and video recorder.

STLS is a truly versatile trainer and can provide total training simulation in one package (Figure 15).

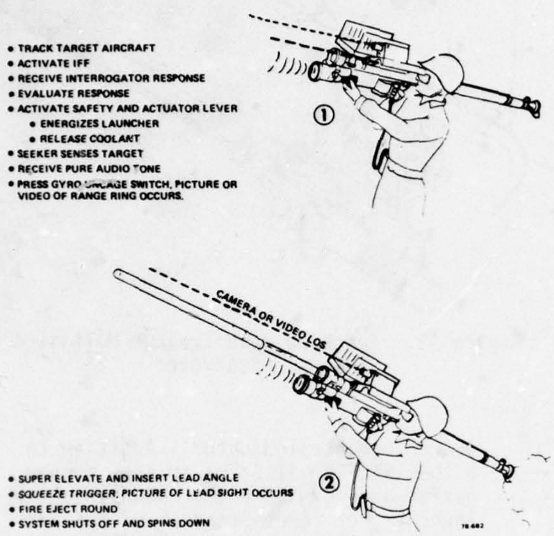


Figure 15. Video Scoring Sequence for STLS

CONCLUSION

A cost-effective training approach for weapon systems that have a high man-weapon interaction has been developed. This trainer, exemplified by STLS for Stinger, provides an added dimension of realism at a fraction of the weapon cost. The only alternative for Stinger is to do no hands on field firing. This does not seem reasonable in light of the requirement for the trainee gunner to kill a high-value jet aircraft on his first firing attempt.

Classroom training is important in Stinger as well as for other weapons. The exposure to the environment, noise of incoming aircraft, knowledge that you must perform in front of your peers and the apprehension associated with firing a live motor on the shoulder cannot be duplicated indoors.

The concept for STLS is simple and has potential for other weapon systems. The prefire sensor/tracking system and any other missile-mounted prefire devices can be integrated into the launch system. The next step is to simplify the missile by removing the guidance, warhead, sustainer motor, etc., so that a bare minimum system remains. Now a real threat can be safety engaged, tracked and fired upon with no danger. This could be a simple but effective training technique for many weapons, but at a minimum, it is key to weapons with high man-weapon interactions.

Consideration needs to be given to this type of trainer early in weapon development so appropriate development and hardware procurement can be accomplished in a timely manner. It can become part of the weapon GSE/logistics package and could be developed with the weapon at minimal cost.

Conclusions from TRASANA Technical Report No. 6-78[1], dated October 1978, concurs in the RELS and STLS concepts through the following statements:

> "Live firing exercises form the most important part of the gunners training, both in the unit and institution as is evidenced by the response to the RELS questionnaires. As one gunner commented, "Live firings puts it all together."
>
> "The RELS training package is an effective training aid to reduce fear and build gunner confidence."

REFERENCES

[1] Department of the Army, U.S. Army TRADOC Analysis Activity, White Sands Missile Range, TRASANA, Technical Report No. 6-78, dated October 1978, Redeye Weapons System, Volume 1 - Executive Summary.

ABOUT THE AUTHORS

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RELIABILITY ENHANCEMENT OF SIMULATORS THROUGH PARTS CONTROL

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INTRODUCTION

One of the major cost factors in the acquisition of a new military weapon system is the electronic equipment and the associated parts used in that system. During the recent past, the proliferation of new electronic parts types have both helped and hurt the cost of electronic equipment in military systems. The ever-increasing development of new electronic devices has made it difficult to maintain current designs. This situation has ultimately resulted in diminishing sources of supply along with reliability and maintenance problems for military equipment.

Past studies in the Department of Defense (DOD) and Congress have concluded that an effective standardization and parts control program during design helps lessen ownership costs and establishes a known reliability level for electronic equipment.

Today, the increasing emphasis of using parts control in military systems has resulted in the issuance of MIL-STD-965, (DOD) Parts Control Program. The Parts Control System is now mandatory for new design or modification in: (1) major weapons systems, (2) end items of equipment where provisioning and follow-on logistics support will be required, (3) any other contract in which the procuring DOD component foresees that life-cycle benefits can be derived. The system promotes efficient use of acquisition dollars by avoiding the need to design and test unnecessary parts while reducing the need for contractor-prepared drawings. MIL-STD-965 also specifies two procedures which allow quick response to a contractor's request for use of a part in equipment design.

Parts control is a proven method of insuring the use of high-reliability military piece parts in the design of new or modified equipment. Lower life-cycle costs are obtained by minimizing the entry of nonstandard parts, thereby eliminating additional logistics costs to the government.

The Defense Logistics Agency designates four Military Parts Control Advisory Groups (MPCAGs) located at: Defense Electronics Supply Center (DESC), Dayton, Ohio; Defense Industrial Supply Center (DISC), Philadelphia, Pennsylvania; Defense General Supply Center (DGSC), Richmond, Virginia and Defense Construction Supply Center (DCSC), Columbus, Ohio. This paper will discuss the DESC MPCAG's experiences with electronic parts where they impact on the reliability and maintenance requirements of military systems. Examples and lessons learned will also be discussed.

FACTORS AFFECTING EQUIPMENT RELIABILITY

The factors contributing to field reliability of military electronics are many, but they generally can be placed in two broad categories. These include external factors such as mission requirements, environmental conditions, maintenance concept, and testing effectiveness. The internal factors include complexity, manufacturing processes, the quality control program, piece-part quality, design concept and workmanship.

INHERENT RELIABILITY

The internal factors actually determine the inherent reliability of equipment. In order to assure the highest degree of inherent reliability, methods such as the following are generally used:

- Complexity Reduction
- Reliability Growth/Design Change
- Failure Mechanism Removal
- Power and/or Temperature Derating
- Better Quality Parts
- Redundant Circuits or Parts

DESIGN TREND

A good example of the trend in avionics equipment is depicted by Figure 1 from the Electronics-X Study.[1] This illustrates an inverse relationship between cost and Mean Flight Hours Between Failure (MFHBF). However, the unit production cost is for equipment procured over a number of years. Figure 1, therefore, indicates the historical trend of increasing complexity versus decreasing reliability for electronic equipment. In one respect, this trend is paradoxical because equipment today is built with large numbers of microcircuits having high inherent reliability. However, studies indicated that the microcircuit improvements were being overspent in the pursuit of ever higher performance goals for equipment.[2] Today, 90% of all electronic functions are capable of being performed with microcircuits. The long-term effect of ever-increasing equipment complexity may well be increased reliability at the

part level with little improvement at the system level.

DESIGN CONCEPTS

Redundancy, parts derating, and design changes are all familiar methods to insure inherent reliability. However, another design concept (which also affects reliability) is the actual arrangement or grouping of parts. The two common concepts of equipment design are heterogeneous (many different part types) and homogeneous (few part types). Computers are generally considered homogeneous in design. For example, you can design 90% of a fairly complex computer by utilizing only 40 types of IC's on 20 printed circuit boards.[3]

However, most military equipment is heterogeneous in design. The result is that many more types of electronic parts must be procured for spares support of complex military systems. In addition, heterogeneous design results in a larger group of failure mechanisms. For example, IC's are known to have 12 common failure mechanisms. Therefore, an assembly only consisting of IC's would have these 12 common failure mechanisms no matter how many IC's are in that assembly. However, if a heterogeneous design of only 25 different parts is built, the failure mechanisms increase rapidly. If each type has an average of 10 failure mechanisms, the total failure mechanisms would be 25 X 10 or 250. This fact alone will cause the failure mechanisms to become much more complex and difficult to avoid when designing large systems. Fortunately, many failure mechanisms of piece parts are eliminated through testing and operational use. This is one reason why equipment and systems reach a plateau of maturity where failure rate is considered constant during the useful life of the system.

METHODS TO IMPROVE RELIABILITY

The external and internal groups listed above are interrelated. This relationship is what ultimately determines the operational field reliability at the military system level. To achieve improved equipment reliability, many programs are used to indicate where a particular system or equipment has failure problems and how to eliminate the failure mechanisms which cause the problems.

One method used today to insure the reliability of equipment includes more realism in equipment testing. For instance, avionics equipment testing now includes simulation of actual vibration and environmental factors the equipment may encounter during a mission. This simulation is done in Combined Environmental Reliability Tests (CERT) facilities. Test Analyze and Fix (TAAF) programs are then used to achieve reliability growth through management changes which eliminate or minimize problems found in equipment.

RELIABILITY GROWTH

In 1962, J. T. Duane of General Electric published his reliability growth data. He illustrated that by plotting the cumulative failure rate versus cumulative operating hours of various complex equipment, a straight-line approximation results with a slope equal to the reliability growth rate alpha (α). Alpha depicts the linear growth rate of MTBF with time on log-log scales. Alpha is used today in reliability testing of avionics equipment and one of the first aircraft radars to use this technique was the APQ-113 series for the F-111 aircraft.

A 1973 research study of the APQ-113 (aircraft radar) documented every aspect of reliability growth from the conceptual phase through deployment.[4] This study also compared the APQ-113 to the earlier APQ-120 used in the F-4E aircraft. These radars were similar in design, functional capability, parts count and acquisition cost; but the APQ-113 series has a specified MTBF 15 times greater than the APQ-120. The demonstrated (contracted) MTBF for the APQ-120 was 4.3 hours or 50% of its requirement while the APQ-113 exceeded its requirement by 12% with a demonstrated 152 hours MTBF.

ALPHA INFLUENCES

One conclusion of the study is that failure mechanisms must be systematically and permanently removed to achieve the specified reliability growth.

The relevant failures found in testing of APQ-113 radars fell into three main categories:

- Design
- Workmanship
- Piece Parts

The distribution of these failure categories is significant since each category averaged approximately one-third of the total failures (Figure 2).

The study indicated that these failure distributions combine to inhibit initial "off-the-board" reliability to approximately 10% of the inherent product reliability predicted from parts performance. A reliability growth goal is generally set by using MIL-Handbook 217, Reliability Prediction of Electronic Equipment, to establish the inherent MTBF figure. This figure is based on the cumulative failure rate at the piece-parts level and depends greatly on the quality of the parts and the environment where the parts

are used.

PART QUALITY EFFECTS

Concerning piece-part quality,this study concluded:

1. Screened parts improved the part failure rate by a factor of 10 to 1 and increased field reliability by no less than 4.

2. The field and platform levels should have parts consistent with JANTX, Established Reliability (ER) and MIL-M-38510. Also, substitution of lower grade parts in field repairs should be prohibited.

3. The monthly logistics support cost for the APQ-113 was less than 1/2 that of the APQ-120 ($299 versus $746).

4. Using tightly screened parts (such as MIL-STD-883 Class B microcircuits) would have removed 50% of the pattern failures. The result would be a 40% increase in the initial MTBF and decreased testing time of 66% with no change in growth rate.

DEVELOPMENT AND USE OF RELIABLE MILITARY PARTS

The Department of Defense has long sought increased piece-parts reliability. As far back as 1960,the Advisory Group on Reliability of Electronic Equipment (AGREE) report recommended that piece-parts specifications should be updated to include measurable reliability requirements. The AGREE report recommendations prompted the development of Established Reliability (ER) specifications. Several other reports pointed out that standardization of piece parts must occur "during the design phase" in order to decrease piece-parts proliferation and increase equipment reliability.

PARTS CONTROL BACKGROUND

Studies such as the APQ-113 research study helped establish the need for high reliability ER, JANTX and MIL-M-38510 piece parts. In response to this need, the Air Force in 1967 developed techniques to control parts used in new design. This led to an Air Force parts control board for the F-111 aircraft in 1968. The same year the Air Force requested that the DESC Directorate of Engineering (DESC-E) serve as parts control advisors to the Air Force Systems Command on selected weapons systems including the F-111 aircraft. The engineers and technicians at DESC-E were chosen since they had long worked as agents for the services writing electronic parts specifications and standards and administering the Qualified Products List (QPL) for those specifications. The advantage of having a centralized corps of DOD parts engineers to respond to the standardization requirements of equipment design programs soon led to a DOD recommendation for a broader DOD Parts Control System. Consequently, in 1971, OASD-I & L directed the expansion of DESC's Parts Control Group to include additional programs. DOD directed a test for parts control in 1971-72 to determine whether it was cost effective. The study indicated a 58 to 1 benefit to cost ratio. The parts control system was then established permanently in DLA and has recently been expanded to include selected supply classes at the Defense General Supply Center, the Defense Industrial Supply Center and the Defense Construction Supply Center.

PARTS CONTROL GOALS

The Parts Control Program seeks to:

- Minimize the variety of parts used in New Design
- Enhance systems reliability and maintainability through the use of reliable parts.
- Keep specifications and standards current with the state of the art.

To achieve these goals, the number of nonstandard parts must be reduced. In addition, the data gathered through MPCAG is used to help keep specifications and standards current. Reducing the number of nonstandard parts in design eliminates many contractor drawings, product testing and items in the DoD inventory.

COSTS FOR NONSTANDARDS

The savings in using a military specification or government documentation to prevent unneeded contractor drawings is tremendous. Commercial parts sometimes place a burden on logistics cost because of special handling or tooling requirements.[5] It has been our experience that 50% of the nonstandard devices submitted to MPCAG for evaluation were already covered by a military specification. It is almost impossible to determine how many source/specification contract drawings are done each year that cover the same part. We have found cases where 40 to 50 OEM drawings covered the same part. Today a drawing for an electronic part can cost anywhere from $500 to $8000 to prepare, depending on complexity. Also, many military contracts have mandatory verification testing of a nonstandard commercial part to assure reliability and safety. The cost of these tests have run from $5000 to $25,000 per test. The average cost of administration, testing, and documentation for each nonstandard part introduced into government inventories is $9,800.[6] Also, nonstandard parts drawings

typically add three new types and styles of devices to the logistics pipeline.[7] *In FY 78*, DESC alone managed over 720,000 electrical and electronic items valued at over one-half billion dollars.

MILITARY PART BENEFITS: SAVINGS AND RELIABILITY

A good example of the logistics potential of standardization during design is a microelectronic linear operational amplifier which was standardized by military specification MIL-M-38510/101. This specification was developed in 1970 in support of the Air Force F-15 program. This part, similar to the 741 operational amplifier, has replaced 17 commercial items (variations of the 741) in the supply system which were previously procured separately (Figure 3).

Figure 3 illustrates how savings are obtained in using military specifications. The use of JM38510/101 allowed the consolidation of 17 similar devices so that only one National Stock Number (NSN) was needed in DOD inventories. The cost to maintain 18 part numbers in inventory each year is almost $3000. This cost was reduced to $165.

In addition, the demand for the nonstandard parts was transferred to the JM38510/101 part. The effect was to drastically reduce the cost for the /101 part from approximately $80 in 1973 to approximately $2 in 1977 (Figures 4 & 5). The drop in price is also due in part to the increase of qualified sources. There are six sources for the JM38510/101 as of January 1979.
Since 1973, cost avoidance has accrued to the systems which used the JM38510/101 devices. The first year cost avoidance for five major systems amounted to $520,000 through design and logistics savings such as prevention of contractors' drawings and tests. An additional savings came through elimination of 80 existing NSNs and prevention of an additional 84 NSNs.

Since first introduced, the JM38510/101 has been used as a replacement 491 times on 125 government weapons contracts. The benefit to cost ratio has been $6,349,612 cost avoidance versus $61,641 in cost or a ratio of 103 to 1.

Another example is the use of parts control in Naval Training Equipment Center (NTEC) simulators. DESC has supported 63 NTEC contracts since 1972. The benefit to cost ratio is $21,725,000 cost avoidance versus $410,350 government and contractor costs or 53 to 1.[8]

The use of many nonstandard electronic parts can significantly increase field failures thereby driving up maintenance costs for equipment. The average cost for a maintenance action of electronic equipment is conservatively estimated at $300 per failure in DOD studies

A microcircuit failure analysis on the F-15 aircraft illustrated the savings JM38510 parts can generate. This study documents analyses of microcircuit removals from assembly to deployment of HUD/IFS equipment used on the F-15.[9] The removal rate of vendor high-reliability microcircuits was 2.7 times higher than the JM38510 parts. Their conclusion was that using JM38510 parts in place of the commercial parts (98% were replaceable) would provide dollar savings of almost 2 to 1 in reducing the costs of rework and microcircuit purchases.

HOW PARTS CONTROL FUNCTIONS

Under DOD Instruction 4120.19, the first integrated DOD procedures and requirements for parts control were placed in MIL-STD-965, Parts Control Program, April 1977. The instruction stated that the services retain final authority and responsibility for approval of parts in the design under their cognizance. The military standard identifies all the federal stock classes for which parts control support is provided. The standard also indicates which Defense Supply Center has the parts information needed by the contractor or service activity.

HOW PARTS CONTROL IS APPLIED IN DESIGN

The key to obtaining maximum standardization during design is through the equipment designer. Designers will use standard parts when they know what is available; can communicate their parts needs to a specialist; and if they can choose parts from a list using current state-of-the-art parts, thereby assuring design freedom. MPCAG meets with contractors during the equipment design phase to review their electronic parts needs. These meetings eliminate many nonstandard parts. Also, contractors make nominations in writing or by telephone. MPCAG reviews the part and/or documentation and gives a recommendation to both the contractor and the military project office. The military office makes the final decision and notifies both MPCAG and the contractor. Contractors are provided the telephone numbers and names of DESC engineers and are encouraged to call directly to discuss parts needs. MPCAG engineers know the latest specifications released and those due for immediate release, as well as qualification status. A response to a telephone inquiry is usually immediate but always is answered within two working days. Written response will usually be answered in seven days or less.

The enforcement of a parts control program does not necessarily mean that all standard

parts used in the design of new equipment should be or could be military specification parts. It does mean, however, that we prefer only selected military and commercial parts be utilized for new equipment. It is not unusual for MPCAG to recommend that a commercial part not be selected due to the availability of a better commercial part.

THE PROGRAM PARTS SELECTION LIST (PPSL)

The parts preferred and approved for use in the design program are then listed on a Program Parts Selection List (PPSL). The PPSL is the list of parts approved for design on a specific contract. It is a dynamic list which has additions as the contract progresses. This is necessary so that the designers will have full access to the parts considered approved, and time to incorporate them into their design.

Another reason why the military parts control group is useful is that we provide and keep current PPSLs on hundreds of contracts. The MPCAG service is used free by military services and contractors engaged in weapons systems which have parts control included. However, MPCAGs will try to help any group with parts problems. Considering that DESC reviewed 53,000 parts on 396 active weapons contracts (FY 78) should indicate the massive amount of work involved. This is one reason why the PPSLs are computerized. This allows the use of the combined parts evaluations as a data base. The data base is used as both history and in forecasting the need for generating new specifications to keep up with electronics state-of-the-art.

SUMMARY - ENHANCED RELIABILITY THROUGH PARTS CONTROL

A statement made in 1971 concerning parts reliability is still relevant today:[10] "In the development of our weapons systems, the old adage 'A chain is only as good as its weakest link' is particularly apropos. Parts make up the system and all parts are required to meet a system's requirements." Most field maintenance actions are the result of failure at the piece part level. The methods used today to insure higher reliability of military electronics include the use of military piece parts because of the known quality levels they exhibit.

The real key to long range reliability and logistics support is to minimize the number of perculiar design parts and increase the population density of standard parts. Peculiar design parts almost never have multiple sources, are usually low-demand items and are expensive. Half the 720,000 items stocked at DESC in 1978 were sole source.

The emphasis on parts control as a means to insure use of reliable military parts in weapon systems is increasing. The importance DOD attaches to parts control is illustrated in the 21 January 1978 memorandum from the Deputy Under Secretary of Defense (OASD). This memorandum to the secretaries of the military services pointed out the benefits of using the MPCAGs to evaluate their parts, and stated that programs subject to DSARC review should state reasons for excluding MPCAGs at the time of review.

The DOD is convinced that parts control saves both time and money without inhibiting design, and that the full potential of the program will be utilized when every DOD system and equipment manager utilizes MPCAG.

REFERENCES:

1. H. P. Gates, Jr., "Electronics-X: A study of Military Electronics with particular reference to cost and reliability," Institute for Defense Analyses Report R-195, January 1974.

2. G. W. Preston, "A Discussion of the ISA Study (P-1244) of the Utilization of LSICs in Military Systems," Institute for Defense Analyses, October 1976.

3. Lyle R. Greenman, "Is Maintainability Keeping Up with Electronics?" Proceedings 1976 Annual Reliability and Maintainability Symposium, January 1976 (Pg. 158).

4. S. G. Miller and R. T. Simpson, "Research Study of Radar Reliability and Its Impact on the Life Cycle Costs for the APQ-113, -114, -120 and -144 Radars," ASD-TR-73-22, April 1973 (pages 4, 8, 33, 167 and 168).

5. Franklin W. Rozell, "Commercial Parts Now, Later or Never," Proceedings Tenth NTEC/Industry Conference, November 1977.

6. Robert E. Depp, "Parts Control A Front End Tool for Long Range Logistics Support Problems," 1978 Symposium Proceedings, Society of Logistics Engineers, August 1978.

7. C. E. Gastineau and R. F. Gonzalez, "Semiconductor Standardization as Viewed by a Government Logistics Supply Center Activity," NEPCON 78 West, February 1978.

8. Donald K. Swanson, "Simulators and Parts Control," Proceedings Eleventh NTEC/Industry Conference, February 1978.

9. D. Dohm, R. J. McCormack, T.E. Utz, "Reliability Analysis of Microcircuits Failures in Avionics Systems (RAMFAS)," RADC-TR-76-3, 1976.

10. Lt. Col. Gordon L. Carpenter USAF, "Air Force Parts Control Program," Defense Industry

Bulletin, Fall 1971.

11. Brigadier General George K. Patterson USAF, "The Weak Link in Defense Logistics," Journal of the Society of Logistics Engineers, Vol 12, No. 4, Winter 1978.

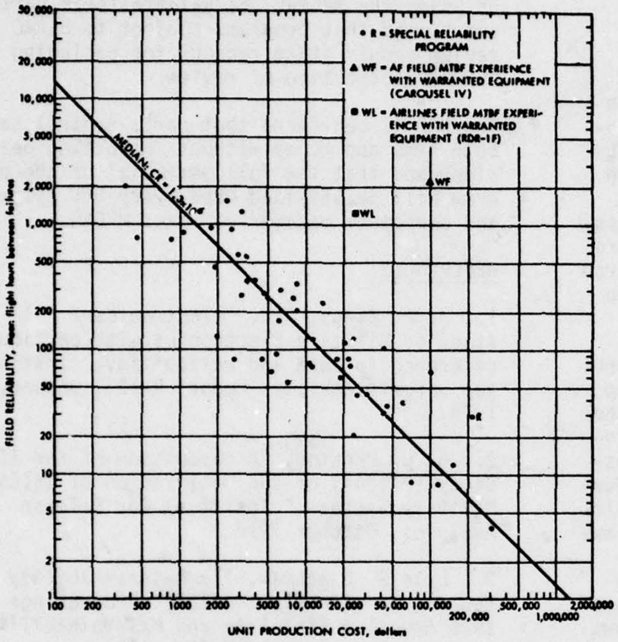

FIGURE 1. Avionics Field Reliability versus Unit Production Cost.

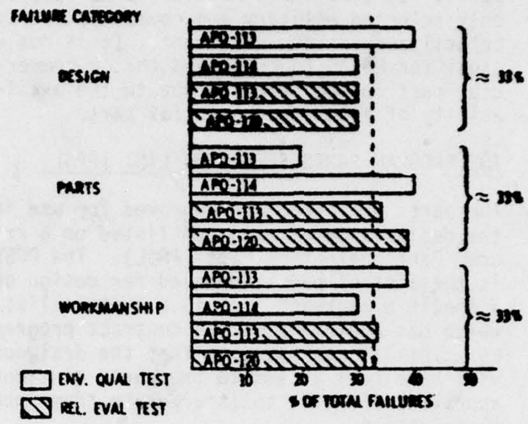

FIGURE 2. Comparative Failure Distribution Environmental Qualifications and Reliability Evaluation Tests.

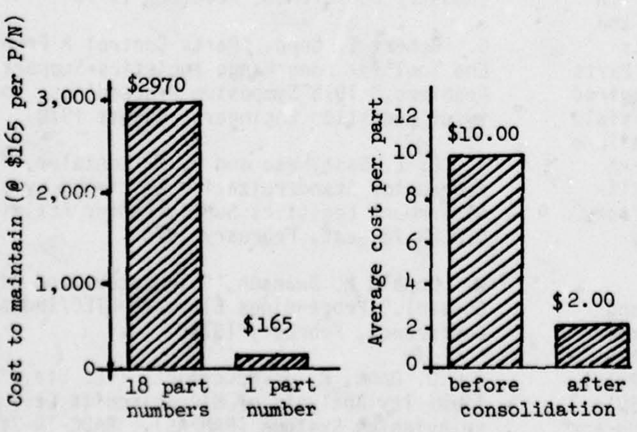

FIGURE 3. Savings attained through consolidation using the JM38510/10101BGC.

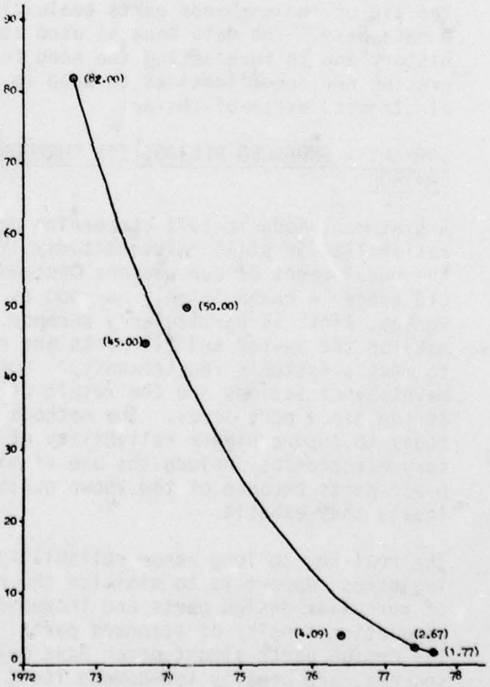

FIGURE 4. Price decline of the JM38510/10101BGC.

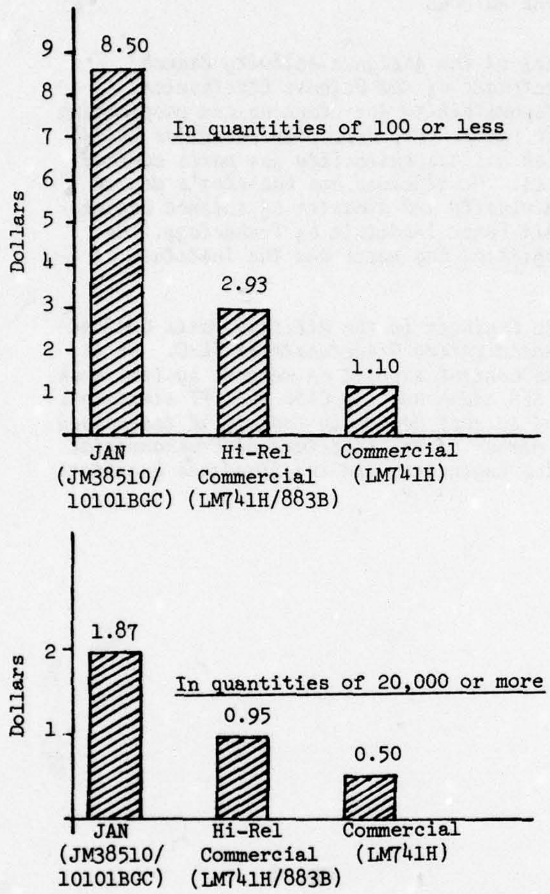

FIGURE 5. Military grade to commercial grade cost comparison.

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SOME CRUCIAL PROBLEMS IN TRAINING TANK GUNNERY SKILLS

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ABSTRACT

Instructional systems development presents many problems for tasks that can be accomplished a variety of ways, and particularly for tasks containing unobservable processes. While unobservable processes are often ignored in instructional systems development, the way in which they are performed can have significant impact on operational performance. Evaluation of a tank gunnery trainer emphasized that considering only observable measures of performance when training gunners to engage moving targets was insufficient. The operational performance in hitting a moving target depends critically on the amount of lead applied. The correct amount of lead, in turn, depends on the target speed. There are, however, several different (unobservable) cognitive strategies for determining lead based on target speed. The current research demonstrates that the cognitive strategy selected for training will have a marked impact on operational performance, and that selection of a strategy to be trained rests on an understanding of underlying psychological processes.

BACKGROUND

The U. S. Army Research Institute at Fort Knox recently evaluated a conduct of fire trainer (COFT) for tank gunnery. The COFT simulated the fire control system of an M60A1, the U. S. Army's main battle tank, and could present the trainee with targets moving at any one of three different speeds.

The behavioral elements of moving-target gunnery technique were analyzed to help determine how training with moving targets should be conducted on the COFT. The analysis revealed that correctly leading moving targets was a critical skill in moving target gunnery.

The M60A1 fire control system does not automatically correct for target motion, so the gunner must manually lead the target to compensate for the distance that the target travels during the round's time of flight. Although the distance traveled by the target along its path is a direct function of both the target speed and range from the firing tank, leads expressed in an angular measure (in mils) are nearly invariant with target range. Hence, for each speed one can specify a value of lead in mils that will be effective regardless of range.

In order to select a lead, the target speed must be known. Without mechanical aids, the gunner must immediately estimate the speed of the target, and know how to relate speed to an appropriate lead value. Both the perceptual skill of speed estimation, and the cognitive skill involved in relating speed to lead are examples of critical, but unobservable processes. In the discussion which follows, the term strategy will refer to a combination of perceptual and cognitive processes used to select a given lead.

Several kinds of lead strategies have been proposed for engaging moving targets. The first, and simplest strategy, requires gunners to apply a standard lead (a different value for each ammunition) to all moving targets, regardless of speed. Current Armor doctrine indorses this strategy in FM 17-12-2, and a standard lead is given for each type of ammunition. The obvious strengths of a standard lead strategy are simplicity in training, and speed of firing the first round against a moving target. However, one must consider that a single lead covers only one small part of the speed range expected from targets on the modern battlefield. The lead specified by Army doctrine is optimal only for targets moving at approximately 10-12 mph; vehicles on the modern battlefield will certainly move at much higher speeds than this.

The second, and slightly more complex kind of strategy, requires gunners to categorize target speed into one of a number of possible speed bands and apply a different lead for each speed band.

Although a categorization strategy places more demand on the gunner than a single lead strategy, it has the potential to cover a range of target speeds much more effectively.

The third, and most complex kind of lead strategy, involves calculation of the amount of lead needed based on the estimated speed of a moving target. Bessemer and Kraemer (1979) recommended such a speed magnitude estimation strategy. Specifically, they recommended that gunners determine a target's speed in miles per hour, divide this speed by ten miles per hour, and multiply the result by a constant; the value of the constant depends on the ballistic characteristics of the ammunition used. Performance with this strategy would depend, of course, on how accurately observers could judge target speed in miles per hour. If

observers could accurately determine a target's speed within a few miles per hour and perform the mental computations necessary, this strategy would be the most accurate of the three.

Clearly, the three strategies all involve some kind of speed discrimination, but differ in the demands each places on the gunner's perceptual system. A single lead strategy demands only that gunners be able to discriminate moving from stationary targets, a categorization strategy involving a small number of categories demands only that gunners make a few discriminations among broad categories, and a speed estimation strategy demands that gunners be able to estimate target speed fairly accurately along a continuum. While the complexity of the discrimination increases going from a single lead to a speed estimation strategy, the potential payoff in terms of target hits also increases, provided that gunners can make the perceptual discriminations each kind of strategy demands.

Since speed discrimination plays a fundamental part in all three lead strategies, the empirical research addressed observers' ability to judge the speed of targets in the COFT being evaluated. Because of the minimal demands of a single lead strategy, the experimenters did not collect empirical data on how well observers could discriminate stationary from moving targets, but concentrated on the speed discriminations demanded by the other two strategies.

METHOD

Subjects. Twenty-eight (28) trainees (25 gunners and 3 drivers) in the One Station Unit Training (OSUT) course at Ft Knox served as observers. Observers were assigned to two groups of 14 each. One group consisted of 13 gunners and one driver; the other consisted of 12 gunners and two drivers. Group assignment was counter-balanced based on the order in which observers came to the experiment. On the first day the first observer was assigned to Group A, and second to Group B, etc., and on the second day the first observer was assigned to Group B, and the second to Group A, etc.

Apparatus. A computer-controlled prototype conduct of fire trainer developed by Chrysler Defense Engineering was used to display moving targets. Figure 1 provides an artist's representation of the simulator's visual display. As Figure 1 shows, the COFT presented trainees with visual displays of a rectangular target that could move left to right or right to left. Observers viewed displays through an eyepiece like that of the primary sight of an M60A1 tank. The experimenter timed the duration of the visual displays with a hand-held stopwatch.

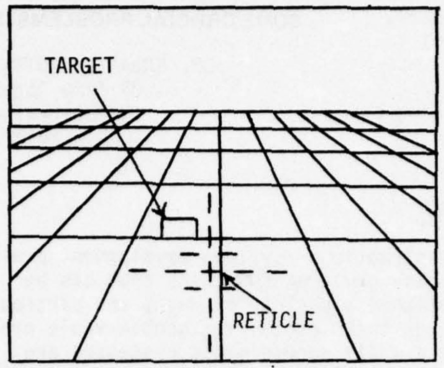

FIGURE 1. ARTIST'S REPRESENTATION OF COFT DISPLAY

Procedure. Each observer was tested individually. Observers sat in front of the simulator's gunner controls and adjusted the sight's focus while viewing the simulator's display of a stationary head-on target at a range of 1500 meters.

The experimenter told each observer that he would see some displays of moving, tank-sized targets and that his task was to judge each target's speed. Each of the two experimental groups received different specific instructions about judging target speed. The experimenter informed the first group (the Categorization group) that the targets would move across their field of view at either a slow, medium, or fast speed at various distances from them, and that they were simply to say on each trial whether the speed of the target was slow, medium, or fast. The second group (the Magnitude Estimation group) was told that the targets would move across the screen at different speeds and at different distances from them, and that on each trial they were to report to the nearest 5 mph how fast the target was moving.

At the beginning of each trial, the experimenter instructed the observers in both groups to look away from the eyepiece, and not to look into it until the experimenter said "go." The experimenter initiated the display and adjusted the reticle crosshairs so the horizontal line of the crosshairs was even with the bottom of the target, and the vertical line of the crosshairs was centered horizontally on the grid. When the target moved to the center of the grid, the experimenter said "go" and began timing the display, as the observer looked into the sight. After approximately five seconds, the display went off and the observer reported the target speed according to the instructions for his group. The experimenter recorded the observer's response and initiated the next trial. Because the target moved at different speeds, and therefore took different times to reach the center of the grid, the inter-trial

interval was varied independently of the target speed. This prevented differences in inter-trial interval from serving as a cue to target speed.

Each observer judged target speed in four blocks of 18 trials each. Each block of 18 trials consisted of targets at one of three different ranges (1000, 1500, or 2500 meters), moving at one of three different simulated speeds (10, 15, or 25 miles per hour), and moving one of two different directions (left or right). Each possible combination of these variables occurred only once in a random sequence during each block.

During the first two blocks of 18 trials, observers received no information about the target range. During the second two blocks, the experimenter told observers the target's range before each trial to determine whether range information produced a sharp improvement in speed judgments.

RESULTS AND DISCUSSION

Speed Judgments. Speed judgments of the Magnitude Estimation group showed large inter-observer variability, and remained variable over all four blocks of trials. Figure 2 shows the speed judgment data of this group separated for trials on which observers received no range information, and trials on which observers did receive range information. The dotted diagonals in these figures indicate perfect performance. Before observers received range information, they underestimated target speed on the average. Average performance came closer to actual target speed after observers received range information, however, the extreme inter-observer variability in both cases discourages much discussion based on average performance. The large amount of variability in speed judgments agrees with that found in previous research (see Haglund and Torre, 1978).

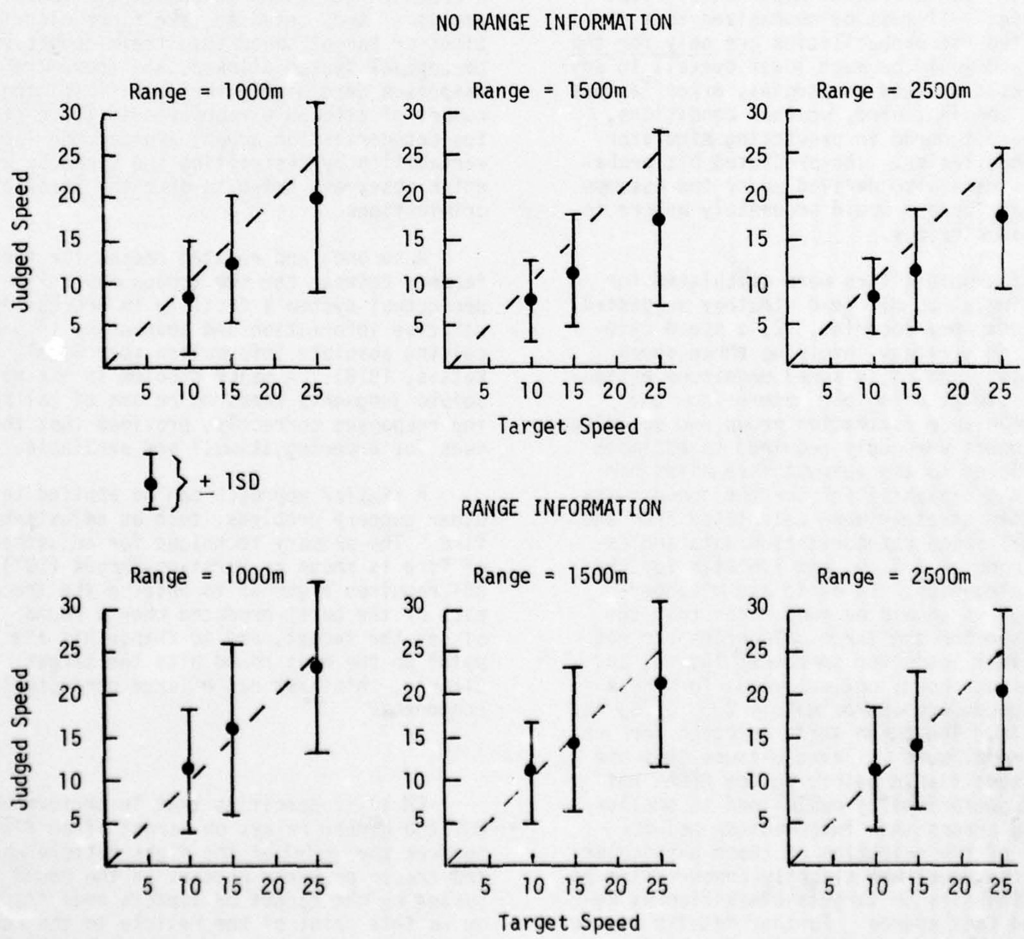

FIGURE 2. SPEED JUDGMENT DATA FOR SPEED MAGNITUDE ESTIMATION GROUP

Observers in the Categorization group identified target speed as either fast, medium, or slow quite well. Observers correctly categorized 76.3% of the target speeds before receiving range information, and correctly categorized 81.2% of the target speeds after receiving range information.

One cannot directly compare performance of the two groups, since the responses required from the two were qualitatively different. However, one can compare the performance of the two groups indirectly by using their speed judgments as input parameters to a model of tank gunnery. Inputting speed judgment parameters allows calculation of predicted hit probabilities and allows one to estimate the operational impact of different kinds of lead strategies.

Speed Judgment Data Applied to a Model of Tank Gunnery in the Simulator. Predicted hit probabilities for the simulator firing Armor Piercing Discarding Sabot (APDS) were calculated for different hypothetical lead strategies. It must be emphasized that the calculated hit probabilities are only for the device and would be much lower overall in any field tests of lead strategies; error factors such as zeroing, wind, weather conditions, etc., were ignored in predicting simulator hit probabilities. The predicted hit probabilities were also derived under the assumption that gunners would accurately adhere to each lead strategy.

Hit probabilities were calculated for (1) a single 2.5 mil lead strategy suggested by current Army doctrine, (2) a speed categorization strategy involving three speed categories, and (3) a speed magnitude estimation strategy, using parameters from the speed magnitude estimation group and assuming that gunners were only required to estimate target speed to the nearest five miles per hour. Hit probabilities for the speed categorization strategy were calculated from the empirical speed categorization data and assumed leads of 2.5, 5, and 7.5 mils for the three categories. To avoid any misunderstanding, it should be made clear that the leads used for the three categories are not the optimal leads for speeds of 10, 15, and 25 miles per hour; optimal leads for these three speeds are approximately 2.5, 3.75, and 6.25 mils. The three leads selected for use in the model were selected because they are easily specifiable points on the M60A1 reticle and operationally would lead to smaller tracking errors than intermediate points. Because of the selection of these particular leads, the model was slightly conservative on predicting hits on targets classified as medium and fast speeds. Further details of the model and parameter estimation from the empirical data are presented elsewhere (Kottas and Bessemer, 1979).

Figure 3 shows the calculated hit probabilities for the three lead strategies as a function of target speed, combined over the three ranges at which speed estimation parameters were collected. Expressing speed judgment performance in terms of hit probabilities makes it clear that a categorization strategy would be the most effective for training gunners using the COFT that was evaluated.

The reason for the difference in performance between the two groups probably reflects the combined operation of two different phenomena. First, the difference almost certainly reflects the operation of an uncertainty effect. Recall that the Categorization group could make one of only three responses--slow, medium, or fast. The Magnitude Estimation group, on the other hand, could make any one of 11 different responses between 0 and 50 mph inclusive. The group estimating target speed in miles per hour was more uncertain about the stimulus that would occur (and hence which response they should make) and tended to use a broad range of the responses available. It was as if they tried to make finer discriminations of target speed than their cognitive or perceptual system allowed, and therefore their responses were highly variable. Limiting the number of allowable responses to three (for the Categorization group) avoided the large variability by restricting the fineness with which observers tried to make the speed discriminations.

A second, and related reason for the difference between the two groups may reflect the perceptual system's facility in processing relative information and inaccuracy in processing absolute information (see Gogel, 1977; Kottas, 1978). A major problem in making absolute judgments seems to be one of calibrating responses correctly, provided that the cues for ordering stimuli are available.

A similar approach can be applied to other gunnery problems, such as adjustment of fire. The primary technique for adjustment of fire is known as Burst-on-Target (BOT). BOT requires a gunner to observe the tracer's path or the burst produced when a round misses the target, and to change his aim point so the next round hits the target. Clearly, this task has a large perceptual component.

FM 17-12 specifies that in performing BOT the gunner relays on target after firing, notices the point of the sight reticle where the tracer or burst appears as the round passes by the target or impacts near it, and moves this point of the reticle to the center of mass of the target. Such a behavioral detailing of the BOT fire adjustment task fails to reveal the critical unobservable processes

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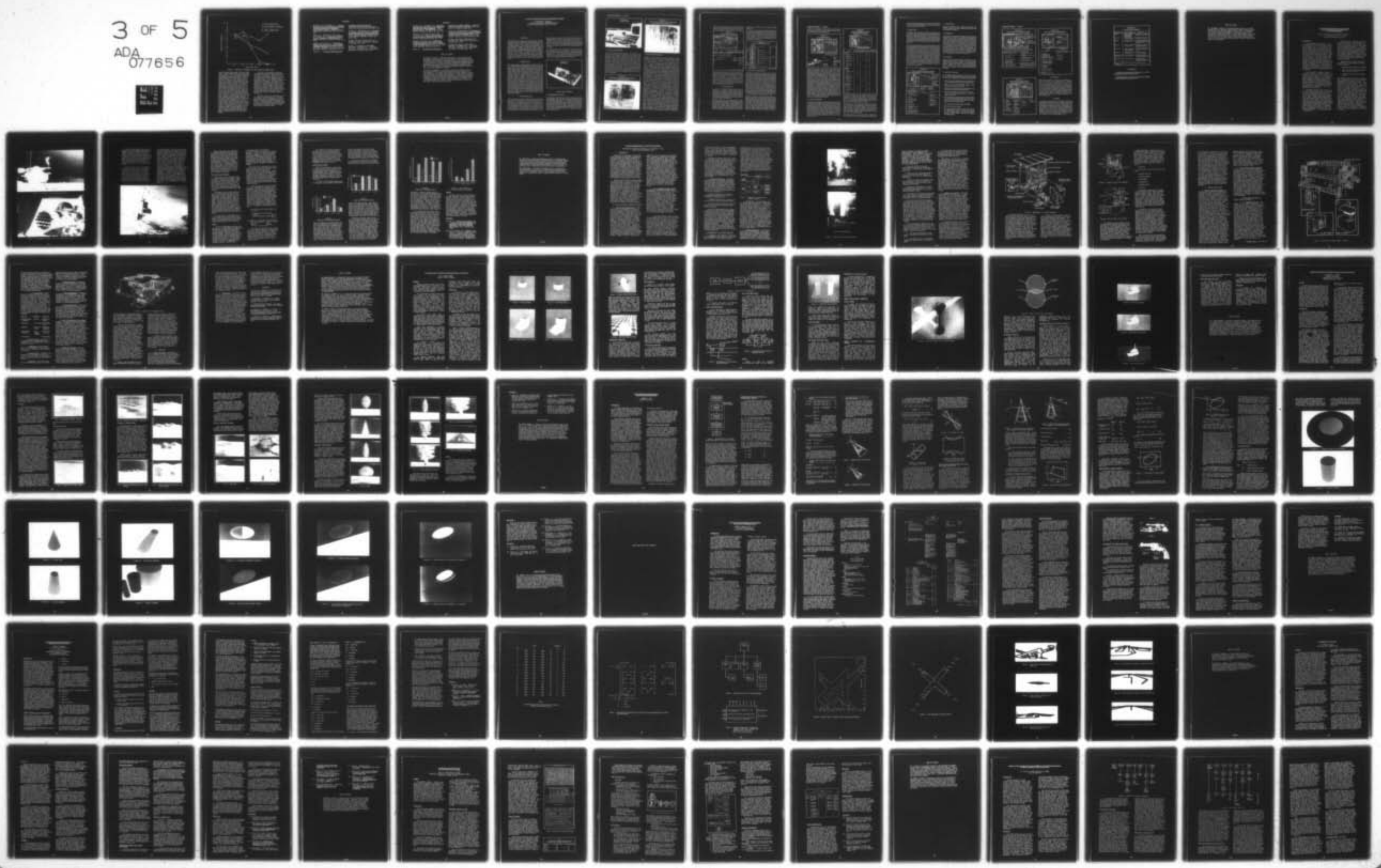

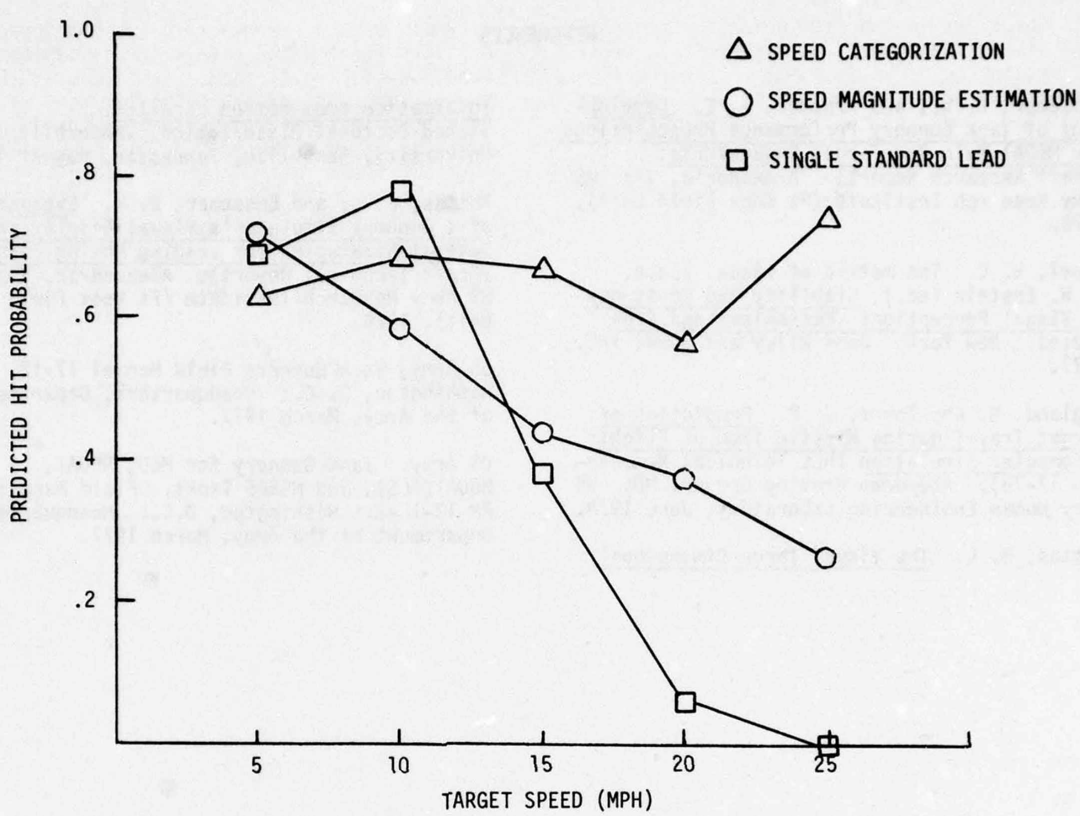

FIGURE 3. PREDICTED HIT PROBABILITIES OVER A RANGE OF TARGET SPEEDS

that might enable the gunner to perform these steps. Three different alternative procedures could be used: (1) a gunner could determine the distance and angle of the burst from the target and move the sight reticle a corresponding distance at a 180° angle from the burst, (2) a gunner could determine the distance of the burst or tracer from the target separately for the horizontal and vertical axes of the reticle, and move the reticle a corresponding distance along each axis, and opposite to the direction of deviation, or (3) a gunner could mentally place an aiming cross on the reticle at the point where the burst struck and simply move that imaginary aiming cross until it is centered on the target. The three strategies obviously have different cognitive and perceptual demands. The first strategy involves distance and angle estimation, the second involves distance estimation along two orthogonal axes, and the third involves the ability to fixate a point in the visual field and maintain that fixation relative to the reticle as it moves. An empirical investigation could assess the error involved in each of these processes for a sample of gunners, and the impact of these errors could be expressed operationally in terms of expected lay error or some other measure.

The kind of investigation described above does not directly address the problem of transfer of training. While it may increase the likelihood of transfer, it is not a substitute for a direct demonstration of the actual impact of the training approach on operational performance. Additional field research will be required to validate the training and transfer effectiveness of a lead strategy or a BOT strategy for tank gunnery. However, if a careful analysis such as the one described above is used in developing an instructional system for a simulator, one can be more confident of conducting a test of transfer that uses the fullest potential of the device.

The above research has implications for the design of training devices. The front-end analysis done in development of training devices typically stops with observable behaviors. The effectiveness of training could be markedly increased if devices are designed to train specific underlying skills rather than merely to simulate a task.

REFERENCES

Bessemer, D. W., and Kraemer, R. E. Development of Tank Gunnery Performance Presceiptions for M60A1 Main Gun Target Engagements. (Draft Research Report). Alexandria, VA: US Army Research Institute (Ft Knox Field Unit), 1979.

Gogel, W. C. The metric of visual space. In W. Epstein (ed.), Stability and Constancy in Visual Perception: Mechanisms and Processes. New York: John Wiley and Sons, Inc., 1977.

Haglund, N. and Torre, J. P. Prediction of Target Travel during Missile Time of Flight: A Computer Simulation (HEL Technical Memorandum 17-78). Aberdeen Proving Ground, MD: US Army Human Engineering Laboratory, June 1978.

Kottas, B. L. The Visual Three-Dimensional Information from Motion Parallax. lished Doctoral Dissertation, Vanderbilt University, Nashville, Tennessee, August 1978.

Kottas, B. L. and Bessemer, D. W. Evaluation of a Gunnery Simulator's Visual Display and Several Strategies for Leading Moving Targets. (Draft Technical Report). Alexandria, VA: US Army Research Institute (Ft Knox Field Unit), 1979.

US Army, Tank Gunnery Field Manual 17-12. Washington, D. C.: Headquarters, Department of the Army, March 1977.

US Army, Tank Gunnery for M60, M60A1, M60A1(AOS), and M48A5 Tanks. Field Manual FM 17-12-2. Washington, D.C.: Headquarters, Department of the Army, March 1977.

REFERENCES

Bessemer, D.W., and Kraemer, R.E. Development of Tank Gunnery Performance Prescriptions for M60A1 Main Gun Target Engagements. (Draft Research Report.) Alexandria, VA: US Army Research Institute (Ft Knox Field Unit), 1979.

Gogel, W.C. The metric of visual space. In W. Epstein (ed.), Stability and Constancy in Visual Perception: Mechanisms and Processes. New York: John Wiley and Sons, Inc., 1977.

Haglund, N. and Torre, J.P. Prediction of Target Travel During Missile Time of Flight: A Computer Simulation (HEL Technical Memorandum 17-78). Aberdeen Proving Ground, MD: US Army Human Engineering Laboratory, June 1978.

Kottas, B.L. The Visual Three-Dimensional Information from Motion Parallax. Unpublished Doctoral Dissertation, Vanderbilt University, Nashville, Tennessee, August 1978.

Kottas, B.L. and Bessemer, D.W. Evaluation of A Gunnery Simulator's Visual Display and Several Strategies for Leading Moving Targets. (Draft Technical Report.) Alexandria, VA: US Army Research Institute (Ft Knox Field Unit), 1979.

US Army, Tank Gunnery Field Manual 17-12. Washington, DC: Headquarters, Department of the Army, March 1977.

US Army, Tank Gunnery for M60, M60A1, M60A1(AOS), and M48A5 Tanks. Field Manual FM 17-12-2. Washington, DC: Headquarters, Department of the Army, March 1977.

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A SIMULATION MODEL FOR BATTALION COMMAND TRAINING

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ABSTRACT

The Combined Army Tactical Training Simulator (CATTS), designed and built by TRW Defense and Space Systems Group, is training battalion staffs at Fort Leavenworth, Kansas, via computer simulation. In this relatively new application, a real-time interactive simulation accepts and executes command decisions made by trainees, and provides real-time reports on the status of forces. The CATTS simulation model was developed from two existing models: the Maneuver and Fire Analyzer (MAFIA) and the Small Independent Action Forces (SIAF). This paper focuses on the major modules within the simulation: terrain, target acquisition, ground fire and engagement, ground movement, air movement and fire, logistics, and command and control.

1. INTRODUCTION

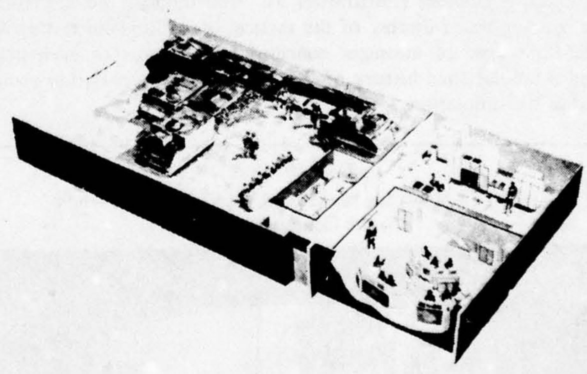
The complex problem of training military personnel is conducted in an environment of ever-changing tactics, equipment, and geography. The classroom lacks the dynamics of the real world, and field exercises are very expensive. Nevertheless, just as pilots must practice flying, military officers must practice the command and control of their units. Training pilots in simulators is now accepted procedure to provide effective training at reduced cost; command training via computer simulation is a relatively new application of this procedure. For this approach, a real-time interactive simulation accepts and executes command decisions made by trainees, and reports on the status of the forces in real-time much as force commanders would report in the real world. Such simulators are founded on the premise that they provide valuable command experience to combat officers and their staffs by allowing them to practice the command and control of their units. The Combined Arms Tactical Training Simulator (CATTS), which was designed and built by TRW Defense and Space Systems Group and is being used for training battalion staffs at Fort Leavenworth, Kansas, is a system that offers a training experience using this new approach.

2. SYSTEM OPERATION

In using CATTS, the battalion commander and his staff (trainees) are housed in a realistic mock-up of a Tactical Operations Center (TOC) that is fully equipped with the normal complement of communications equipment (Illustration 1). Using this equipment, commands are given to and reports are received from a set of controllers who act as subordinate, adjacent, and higher commanders (platoon, company, battalion, and brigade). Instead of the subordinate commanders dealing with real troops, enemies, and environment, however, they interact with the computer simulation model. The key to the system is the model: it simulates the tactical operation and generates a time history of status reports much as the operational units would during critical events. This information is communicated by the model to the controllers, who then communicate over simulated radio nets to the trainees.

The trainees interpret this information, make decisions, and communicate their decisions to the controllers. The controllers input these commands to the model using color interactive graphics (Illustration 2). This model therefore generates real-time commands as the scenario unfolds; it provides the vehicle which executes the command decisions made by the trainees.

Illustration 1.
CATTS Overview

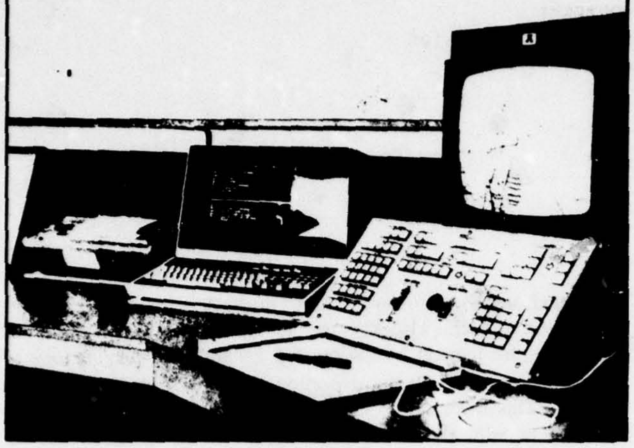


3. SIMULATION OVERVIEW

3.1 DEVELOPMENT HISTORY

The simulation model described below was developed from two existing models. The core of the model is the Maneuver and Fire Analyzer (MAFIA) model.[1] The MAFIA was made interactive, and high resolution terrain, weather, and target acquisition modules from the SIAF model[2] were added. Several new modules were developed to include a high-resolution movement model, logistics consumption modules, air support, and real-time command and control modules; these were integrated to produce the final CATTS model.

Illustration 2.
Controller Station



3.2 GENERAL DESCRIPTION

The CATTS model has several descriptors: high resolution, two-sided, free form, interactive, battalion level, stochastic, and fixed-time step simulation. Inputs include terrain and vegetation data, weather scenarios, definition of simulated units, TOE equipment of each unit, weapons effects data for each weapon against each equipment type, the fire support plan, and the operations plan. The simulation accepts inputs and changes to the tactical parameters which are under the control of the command group throughout its execution. Inputs are provided via color interactive graphics (Illustration 3). The outputs include visual, color, map-based display of the tactical operation (Illustration 4), real-time flow of messages concerning the status of each unit, and a tabular time history of the activities and events that occurred in the simulation.

Illustration 3.
CATTS Menu for Inputting Unit Firing Commands to the Computer Model

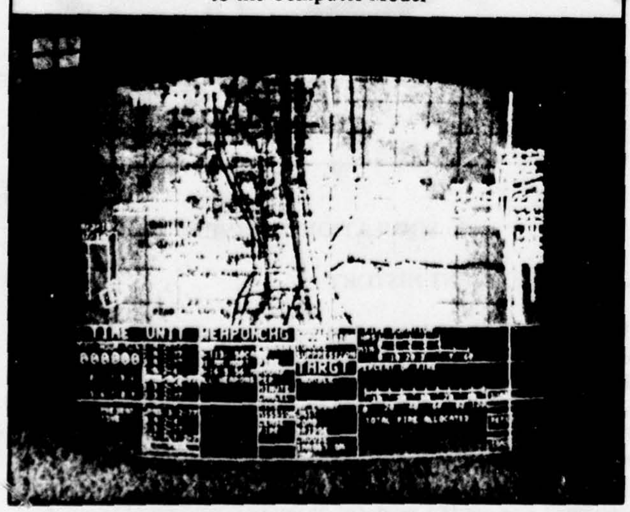
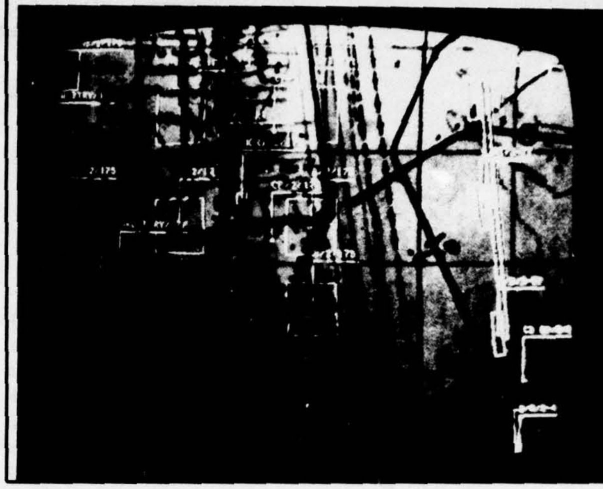


Illustration 4.
Computer Output Graphic Showing Area Occupied and Location of Red and Blue Units



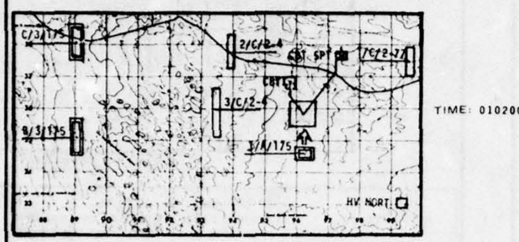
3.3 SIMULATION OPERATION

Illustration 5 is an example of the model's operation. At time 010200, for instance, red unit I/A/175 detects blue unit CBT/2-77; this event occurs as a function of terrain, weather, detection devices manned by 1/A/175, and the activities of both units. If the model determines that this detection occurred, it sends a message on the alphanumeric display (Illustration 3) to the red controllers who decide on the appropriate action. (Note: trainees are not involved in red unit decisions. Instead, these decisions are made by a red control group). Many alternatives are available and the one selected depends on the scenario. If the red controllers playing the role of first platoon A company 175th battalion decide to fire on the combat trains, they input the fire command to the model which executes the fire mission at the selected time. Meanwhile, other detections, fire missions, etc., might be occurring between other simulated units (e.g., CBT/2-77 might detect 1/A/175). At the time the fire mission is executed, the model generates another message indicating the CBT/2-77 is receiving fire. This report goes to the blue controllers playing the part of the commander of CBT/2-77, who call the battalion to report they have been fired upon by an unknown enemy force. At this point, the battalion trainee team (players in Illustration 1) respond with one of the several alternatives identified in Illustration 5. Perhaps, as a result of a previous decision, a blue supporting unit is out of range or is commited to another operation: feedback on past decisions are indirectly related to the command group as a reduction in available alternatives. Meanwhile, as the battalion team selects a course of action, the model continues calculating casualties and ammunition consumption associated with the engagement; delays in the decision therefore influence these results. As shown in Illustration 5, the battalion commander group could send unit 2/C/2-4 to engage. The movement would take time, however, and because this is a function of terrain, weather, time of day, and unit equipment, feedback on a movement decision is reflected back to the battalion command group in terms of cumulative casualties sustained by CBT/2-77 while awaiting the support. Alternatively,

CBT/2-77 could be ordered to move, etc. The CATTS system is therefore capable of executing a wide range of free-form orders and is not constrained by canned tactics of fixed decision rules.

Illustration 5.

Sample Simulation Model Operation



TIME	MODEL	RED CONTROLLERS	BLUE CONTROLLERS	PLAYERS
010200	1/A/175 DETECTS CBT/2077 →	DETECTION ALERT		
010201	1/A/175 ENGAGES CBT/2-77 ←	FIRE CONTROL		
	CBT/2077 RECEIVES FIRE →		CONTACT ALERT →	CONTACT REPORT
010205	3/C/204 GETS ROUTE	←	MANEUVER CONTROL →	3/C/2-4 TO ENGAGE (2/C/204 TO ENGAGE)

Notice that while there might be a number of "good" tactics to be applied, there is no "school solution" to this particular example problem. Notice also that the model does not give scores or indices of performance to the trainees; it simply reports, much like the real units would. Firepower scores are not used, either - the model simply calculates statistics covering the status of the forces but makes no attempt to score the trainees. The complete training experience, both audio and video, is recorded on tape for playback after the training session so the battalion staff can review its decisions.

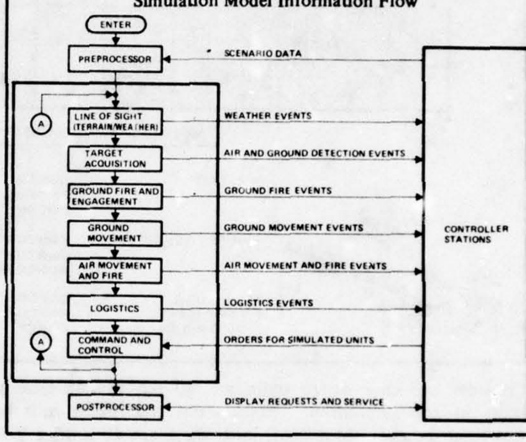
4. SIMULATION MODULES

An overview of the model's information flow is shown in Illustration 6. A preprocessor accepts scenario data from the controllers that can include the number of simulated units to be included in the exercise; the location, supply, strength and mission of each of the simulated units, the weather conditions; and the mission and task organiztion of each unit. The preprocessor updates the data base which contains files describing the attributes of each of the simulated units.

During the execution, the model cycles through the modules shown in Illustration 6 on a fixed time-step basis that is normally set at one minute. As calculations are made within each module, the data base is updated and the tactically significant results are sent to the controller's displays for subsequent voice communication to the trainees. Trainees react to the situation and formulate their orders. Trainees' commands are voice-communicated to the controllers who input these commands to the command and control module using color interactive graphics (Illustration 4).

The data base is stored each minute of the model operation. After the simulation run is completed, the postprocessor (Illustration 6) allows these data to be displayed on the controller's monitor for an instant replay of the operation. In this way the trainees can view and discuss the exercise. A brief overview of various interactions considered in some of the CATTS modules follows. This discussion steps through the modules and describes a few of the parameters that are modeled.

Illustration 6.
Simulation Model Information Flow



4.1 LINE-OF-SIGHT TERRAIN MODULE

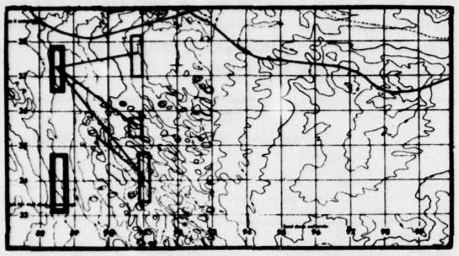
The first step in the Illustration 6 sequence of calculations involves determining line of sight between opposing units. A unit may fail to see another unit because it is masked by relief or concealed by vegetation. These factors must be accounted for in the simulation because, if modeled correctly, they can provide feedback to the trainees on the proper tactical use of terrain. Relief (the folds and undulations of the ground) is modeled by first dividing the area of operations in grid squares 25 meters on each side. The altitude of each point in each square is available from U.S. Army digitized terrain tapes which are used to provide inputs to the model. The area of operation in CATTS is approximately 30 by 100 kilometers; consequently, there are approximately 4.8 million such points in the CATTS relief data base. Given this data base and two points on the map, the line of sight between the two points is calculated using an algorithm that fits a quadralateral surface between the points of each of the 25 x 25-meter grid squares. The model calculates both cover and partial cover due to relief (i.e., the line of sight may be partially cut off due to relief).

Vegetation is modeled by considering 14 vegetation classes, each consisting of grass, brush, and trees of different sizes and densities. Clumps of brush and trees are assumed to be randomly distributed within each class, while grass is modeled as an extension of relief (Illustration 7). The different areas of vegetation are represented by rectangles, circles, and polygons, which are input into the vegetation data base; CATTS provides for 300 vegetation polygons. The line-of-sight calculation considers those classes of vegetation it passes through, then calculates the probability that the target is totally concealed or not concealed. Partial concealment is estimated from these two calculations. As shown in

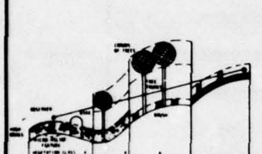
A SIMULATION MODEL . . . Continued

Illustration 7, line-of-sight can be interrupted by combinations of tree crowns, tree trunks, clumps of brush, clumps of grass, and cultural features such as dikes and walls.

Illustration 7.
Line-of-Sight Calculation



LINE-OF-SIGHT CALCULATION



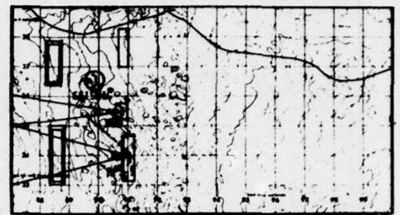
- RELIEF — COVER, PARTIAL COVER
- VEGETATION — CONCEALMENT, PARTIAL CONCEALMENT
- CULTURAL FEATURES, OBSTACLES — COVER, PARTIAL COVER

Consider the case where there are 40 red and 40 blue ground units in the simulation. Since each red (blue) unit has the potential see every blue (red) unit, there are 40 x 40 x 2 = 3200 line-of-sight calculations to be made each time step of the model. (Note: vegetation concealment must be made from both directions because it is direction-dependent). This estimate of 3200 assumed the line of sight is run from center-of-mass to center-of-mass of each unit. The number of calculations increase as the number of points within each unit are increased. When considering ten observation points within each unit, for example, the total number of line-of-sight calculations per time step would be 320,000. An estimated 1000 instructions per line of sight calculation yields a processing rate of 5 million instructions per second for line of sight alone. This is one example of a situation where the fidelity of such tactical models as CATTS is not necessarily limited by our ability to model tactical warfare, but is, instead, constrained by the speed of the available computers. In CATTS, distance checks are made to compute feasible sets of red and blue units (i.e., those that have the potential to detect each other). The line-of-sight calculation is then run between units in these sets to cut down model running time.

4.2 TARGET ACQUISITION

At this point in the simulation the line of sight between all feasible red and blue units has been made. Those units not covered or concealed from each other are candidates for detection by such line-of-sight sensors as vision and radar. CATTS also models aural detection (which acts as a cue for visual detection) and unattended sensors. Illustration 8 shows the sensors modeled in CATTS and the interactions treated. Consider visual detection as an example: the ability to detect depends on the target type and its activity. If the equipment is large, moving, and/or firing, it is easy to detect; if it is camouflaged and operating at night only, it is more difficult to detect.

Illustration 8.
Interaction Considered in the Target Acquisition Modules Illustrated



ITEMS	VISUAL DETECTION	AURAL DETECTION	RADAR	UNATTENDED SENSORS
TARGETS	√	√	√	√
EQUIPMENT TYPE	√	√	√	√
NUMBER OF EQUIPMENTS	√	√	√	√
MOVEMENT RATE	√	√	√	√
FIRING STATUS	√	√	√	
DISPOSITION	√			
CAMOUFLAGE	√			
OPERATIONAL STATE	√	√	√	√
OBSERVERS				
NUMBER	√	√		
MOVEMENT RATE	√		√	
RANGE	√	√		
SUPPRESSION	√		√	
AREA OF RESPONSIBILITY	√			
EQUIPMENT		√		
FIRING STATUS		√		
SETUP TIME			√	
ENVIRONMENT				
WEATHER	√	√		
TIME OF DAY	√		√	
CONCEALMENT	√		√	
COVER				√
SOIL TYPE				

As shown in the illustration, the activity of the observer also influences the outcome of visual detection. If the observers are moving and are partially suppressed by fire, detection is less likely. As the number of observers increases, and the target observer range decreases, detection is more likely.

The third category of factors influencing detection is the environment. Weather, time of day (light level), and terrain all influence visual detection in the CATTS simulation. Eleven classes of weather are played, varying from very clear to fog. These classes define meteorological visibility which influences visual detection. Light level includes starlight, one-quarter moon, half moon, full moon, dusk, dawn, and full sunlight.

The sensors and factors shown in Illustration 8 are considered in the CATTS model and provide variables that yield different out-

comes to the trainees depending upon how they operate tactically and how well they take advantage of the environmental conditions of terrain, weather, and time of day.

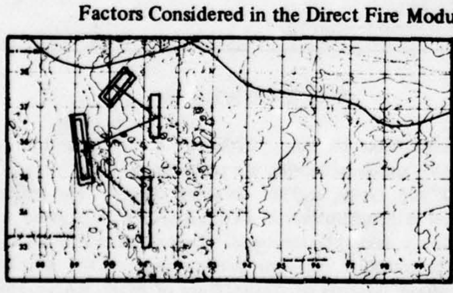
4.3 DIRECT FIRE

At this point in the simulation, the detection calculation has been made and all units that detected each other are flagged. Since detection is modeled probabilistically, it could turn out that units which detect one cycle of the model do not detect each other on the next cycle. The model accounts for this by remembering that a detection occurred and by setting a state-of-knowledge variable which is degraded exponentially with time if no subsequent detections occur.

Once units have detected, they may conduct fire missions depending on their operational states and mission. Illustration 9 shows that this decision can be programmed to be made automatically by the model, or can be made by the trainees and communicated to the controllers for input to the model. If the model makes the decision, a variety of different situations have to be accounted for. For example, a unit could have detected several other units, and a decision would include who to fire at and how to allocate fire among the detected units. Criteria used for this automatic decision include unit position advantage, target equipments, range, and the number of equipments detected. If the trainee makes the decision, he indicates to the controllers how the fire is to be conducted and the controller inputs this to the computer. In either event, the model calculates casualties based on the factors shown in the illustration.

Illustration 9.

Factors Considered in the Direct Fire Module



SITUATION:

UNIT HAS DETECTED TWO TARGETS

PROBLEM:

HOW SHOULD FIRING BE CONDUCTED?

MODEL DECISION

AUTOMATIC ALLOCATION OF FIRES TO TARGETS

- TARGET UNIT POSITION ADVANTAGE
- TARGET EQUIPMENTS
- RANGE
- NUMBER OF EQUIPMENTS DETECTED

RATE OF FIRE

- MISSION
- SUPPRESSION
- NUMBER OF MANNED WEAPONS
- AMMUNITION LEVELS

AIMED VERSUS AREA FIRE

- OPERATIONAL STATE

CONTROLLER DECISION

- % OF FIRE
- RATE OF FIRE

CASUALTY ASSESSMENT

- BALLISTIC ERRORS
- RANGE
- WEAPON/TARGET LETHALITY
- TARGET MOVEMENT STATUS
- DISPOSITION/ SUPPRESSION
- AREA OCCUPIED
- NUMBER OF MEN/ EQUIPMENT

4.4 SUPPORT FIRE

Support fire (Illustration 10) is treated in a similar manner, with either the model or the trainees establishing the priority of conflicting support fire missions.

4.5 MOVEMENT

At this point in the simulation, line-of-sight, detection, and firing decisions and actions have been established for all opposing units. This has been done based on a fixed location of each unit on the map. The model treats units as fixed during each time step and accounts for movement by displacing each unit the distance it would move in a time step. For example, if a unit's movement rate is calculated to be 10 km/hr, and a time step is one minute, the unit moves 166 meters in a minute. During execution of the movement module, the unit is displaced by this amount. Displacement occurs by having the unit location data updated in the units attributes position of the unit file. Illustration 11 shows the different types of movement modeled in CATTS and the parameters considered in the calculation of movement rate.

4.6 LOGISTICS

Finally, the logistics module (Illustration 12) updates the current logistics status of each piece of equipment in each unit to include remaining fuel and maintenance status. The model allows for automatic resupply between units or controller-directed resupply where a controller uses a menu to transfer equipment/supplies from one unit to another. Factors considered are shown in the illustration.

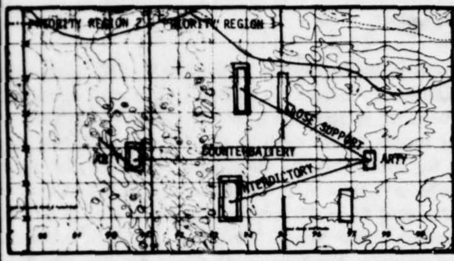
4.7 ADDITIONAL FACTORS

The preceeding discussion presented an overview of the simulation to provide an understanding of its basic operation. Following are other factors considered in the model but not included here:

1. The model treats reassignment of personnel to equipment if personnel casualities on a specific piece of equipment occur.
2. Troops can be in several vulnerability classes to include standing, crouching, prone, in foxholes.
3. Destruction of command and control headquarters affects the tactical effectiveness of the appropriate unit.
4. Individual equipment within each unit is modeled to account for the different performance of units due to equipment differences.
5. Each equipment type is allowed to move and fire at different rates which automatically change when certain conditions are satisfied. This allows the evaluation of tactical differences due to equipment operation.
6. Air movement sensors and fire support are modeled.
7. Night vision devices are modeled.
8. The model considers automatic command and control and automatically changes the state of units based on the current tactical situation. This feature is overriden when the controllers desire to exercise their command and control options.

A SIMULATION MODEL . . . Continued

Illustration 10.
Factors Considered in the Support Fire Module



SITUATION:

UNIT HAS CONFLICTING SUPPORT FIRE MISSIONS

PROBLEM:

WHICH MISSION HAS PRIORITY?

CONTROLLER OVERRIDE CAPABILITY SAME AS DIRECT FIRE

MISSIONS OF SUPPORT FIRE UNITS

1) FINAL PROTECTIVE FIRES
2) CLOSE SUPPORT FIRE
3) INTERDICTORY FIRE
4) COUNTER BATTERY FIRE
5) GENERAL SUPPORT — SPECIFIC TARGET
6) GENERAL SUPPORT
7) NON-FIRING SUPPRESSED
8) NON-FIRING MOVEMENT

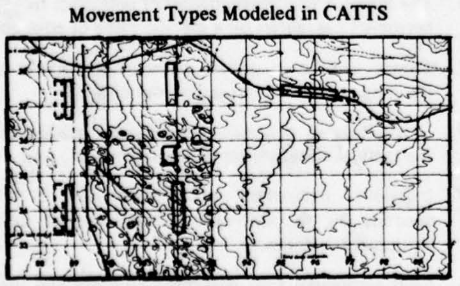
TARGET CATEGORIES

1) ENGAGED/CLOSE SUPPORT FEASIBLE
2) ENGAGED/INTERDICTORY FIRE FEASIBLE
3) NOT ENGAGED BUT HAS SUPPORT-FIRE WEAPONS
4) NOT ENGAGED
5) SUPPORT FIRE NOT FEASIBLE

PRIORITIZED SUPPORT FIRE REGIONS

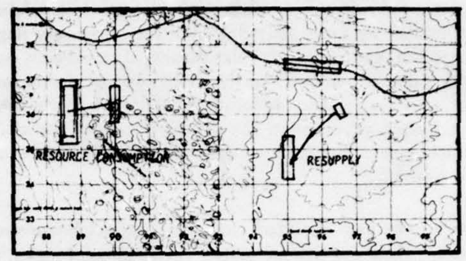
FIRE ALLOCATION CRITERIA ARE OTHERWISE SAME AS DIRECT FIRE

Illustration 11.
Factors Considered in Each of the Four Movement Types Modeled in CATTS



ON-ROAD	CROSS COUNTRY	AIR	WATER
• EQUIPMENT TYPE	• EQUIPMENT TYPE	• EQUIPMENT TYPE	• EQUIPMENT TYPE
• NUMBER OF EQUIPMENTS	• NUMBER OF EQUIPMENTS	• FLIGHT PLAN	
• SLOPE	• SLOPE	• WEATHER	
• MISSION	• MISSION	•	
• SUPPRESSION	• SUPPRESSION		
• TIME OF DAY	• TIME OF DAY		
• OBSTACLES	• OBSTACLES		
	• VEGETATION		
	• SOIL TYPE		

Illustration 12.
Model and Controller Logistics Functions



MODEL

- FUEL CONSUMPTION
  - FUEL TYPE
  - MOVEMENT RATE
  - EQUIPMENT TYPE
  - ON-OR-OFF-ROAD
  - MAINTENANCE OVERHEAD
  - RESUPPLY OVERHEAD
- MAINTENANCE ATTRITION
  - EQUIPMENT MEAN-TIME-BETWEEN-FAILURES
  - STOCHASTIC SAMPLING
- READINESS CONDITION
  - PERSONNEL
  - EQUIPMENT
- PERSONNEL ASSIGNMENT
  - EQUIPMENT PRIORITY
- ATTRITION
- AMMUNITION EXPENDITURE

CONTROLLER

- RESUPPLY (TO OR FROM EXISTING UNIT HIGHER COMMAND)
  - MEN
  - EQUIPMENT
  - AMMUNITION
  - PERSONNEL

5. LIMITATIONS

Model restrictions include: 2700 sq. km of operating area, a total of 99 simulated units, 80 equipment types, 14 vegetation classes, 9 soil types, and 11 weather classes. The majority of the model is programmed in FORTRAN IV, but some routines are in Xerox assembly language. Xerox assembly language was utilized to optimize real-time performance on the Xerox Sigma 9. The model consists of 29,000 lines of FORTRAN. The interactive programs consist of 80,000 machine language instructions and the compiler constructs approximately 110,000 machine language instructions from the 29,000 lines of FORTRAN, yielding an estimated 190,000 machine language instructions for the total CATTS software.

6. SUMMARY

The simulation described provides the command and staff group with battle status information in terms of real-time and real-world observables, and accepts and executes real-time decisions made by the battalion commander and his staff. The simulation is currently being used to train officers at Fort Leavenworth, Kansas; Illustration 13 is a summary of the training benefits derived from simulating the various items shown. The premise that command simulation training is a cost-effective augmentation to conventional training is currently being evaluated. CATTS is an important first step in this new, potentially high-payoff area.

Illustration 13.

CATTS Features and Benefits

REAL WORLD	SIMULATED WORLD	BENEFITS
TERRAIN	• DIRECT CORRESPONDENCE BETWEEN MODELED AND REAL TERRAIN	FEEDBACK ON PROPER/IMPROPER USE OF TERRAIN
WEATHER	• DETAILED SIMULATION OF WEATHER	FEEDBACK ON DECISIONS AFFECTED BY WEATHER
SENSORS	• USES APPROVED PERFORMANCE DATA	FEEDBACK ON THE EFFECTS OF RECONNAISSANCE AND INTELLIGENCE GATHERING ACTIVITIES
WEAPONS	• PORTRAYS DIFFERENT WEAPONS SYSTEM	FEEDBACK ON PROPER/IMPROPER APPLICATION OF COMBINED ARMS FIRE
MOVEMENT	• BASED ON TERRAIN, WEATHER, FORMATIONS, EQUIPMENT,	FEEDBACK ON SCHEMES OF MANEUVER, MOVEMENT PLAN
LOGISTICS	• CONSUMPTION BASED UPON TERRAIN,	LOGISTICS IMPACT ON TACTICAL DECISIONS
INFORMATION/DECISION FLOW	• REAL TIME SIMULATION OF OPERATION	REALISTIC TIMING OF INFORMATION FLOW FOR VARIABLE STRESS LEVELS
RED FORCES	• TWO-SIDED MODEL	RED FORCES CAN DYNAMICALLY REACT TO TACTICAL DECISIONS

SIMULATED OPERATION IS TRACEABLE AND VERIFIABLE BY THE TRAINEES

7. REFERENCES

1 Users Manual for Maneuver and Fire Analyzer, U.S.A. Combat Developments Command, 20 October 1969.

2 Small Independent Action Forces (SIAF) User's Manual, Advanced Research Projects Agency, 1972.

ABOUT THE AUTHOR

DR. ALEXANDER W. DOBIESKI is currently Systems Engineer on the BETA System, which is a tactical, computer-based, sensor processing system scheduled for test and deployment in Europe in 1980. Dr. Dobieski has 17 years experience in simulation, operations research, and computer and systems architecture. He has authored numerous technical publications in simulation, queueing theory, and electronic design. He received a B.S.E.E. degree from the University of Connecticut, an M.S.E.E. from the University of Utah, and Ph.D. from the University of California, Los Angeles.

AIR-GROUND ENGAGEMENT SIMULATION (AGES): REALISTIC AND EFFECTIVE TRAINING FOR AIR DEFENSE PERSONNEL

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INTRODUCTION

The development of team skills of US Army combat units has traditionally involved "by the numbers" crew drills or field training exercises (FTX). In both methods, realism or training fidelity has been marginal. Field training exercises require a rigid adherence to imaginary situations administered by the subjective decision of umpires. The FTX often includes preplanned scenarios where units perform on cue and the tactical behaviors of leaders or individual soldiers have relatively little to do with the mission outcome. As casualties are assessed using an arbitrary decision process, soldiers often engage in behaviors that would be highly impractical in combat (i.e., frontal assaults of prepositioned defenses). There were essentially no incentives to avoid the line of incoming fire, because the consequences were ill defined.

Early attempts at improving realism through simulation in a military context concentrated on individual skills such as the flight training simulator. In a combat situation, however, a tactical unit's performance depends on individual soldier skills and on a complex of team collective skills, the nature of which has been much debated (Collins, 1977). The training of collective skills, including the coordination of activities among unit elements, is the focus of Engagement Simulation (ES).

Engagement Simulation was initially designed for the training of small Army infantry units where emphasis was placed on a realistic training environment and on objective casualty assessment procedures (Root & Erwin, 1976). SCOPES (Squad-Combat Operations Exercises-Simulation) centered on the training of rifle squads. It involved two-sided free-play exercises where outcomes were not preplanned but depended on the collective behavior of the squads and individuals who composed them on both sides of the engagement. SCOPES was enlarged to include platoons and companies of infantry, armor and antiarmor components. It then became known as REALTRAIN.

AGES (Air-Ground Engagement Simulation) was developed based on the groundwork of SCOPES and REALTRAIN. AGES provides a motivating and challenging training environment for short range air defenders. In times where training ammunition is in short supply and training time is at a premium, AGES was felt to offer considerable potential for providing a simulated environment in which air defenders could emit and practice tactically relevant behaviors. It also provides a feedback system to make knowledge of results (KR) available at the end of each training sequence.

AGES has three key dimensions which discriminate it from previous air defense training programs:

- Weapons effects signature simulation
- Near real-time casualty assessment based on clear-cut rules
- After Action Reviews (the feedback system).

Each weapons system for both air defense and for air aggressors (the AH-1Q Cobra attack helicopter normally plays this role) is equipped with a signature simulator. These simulators serve two purposes. First, they place a firing unit in the same condition it would be in a given combat situation. If it fires, it discloses its position. This factor is especially important to ground air defense units, which must decide whether to fire again or move out of harm's way. Without signature simulation,they can unrealistically remain where they are. The second purpose of signature simulation is to provide air defense crews with the impression that they are actually doing something with their weapon besides sitting there and watching aircraft fly by. Three air defense weapons are used in AGES: the Vulcan gun, the Chaparral missile, and the Redeye missile. Each has its own distinctive simulation device. A picture of a Chaparral firing at an incoming aggressor is presented in Figure 1.

Figure 1. A Chaparral Fires the Signature Simulator

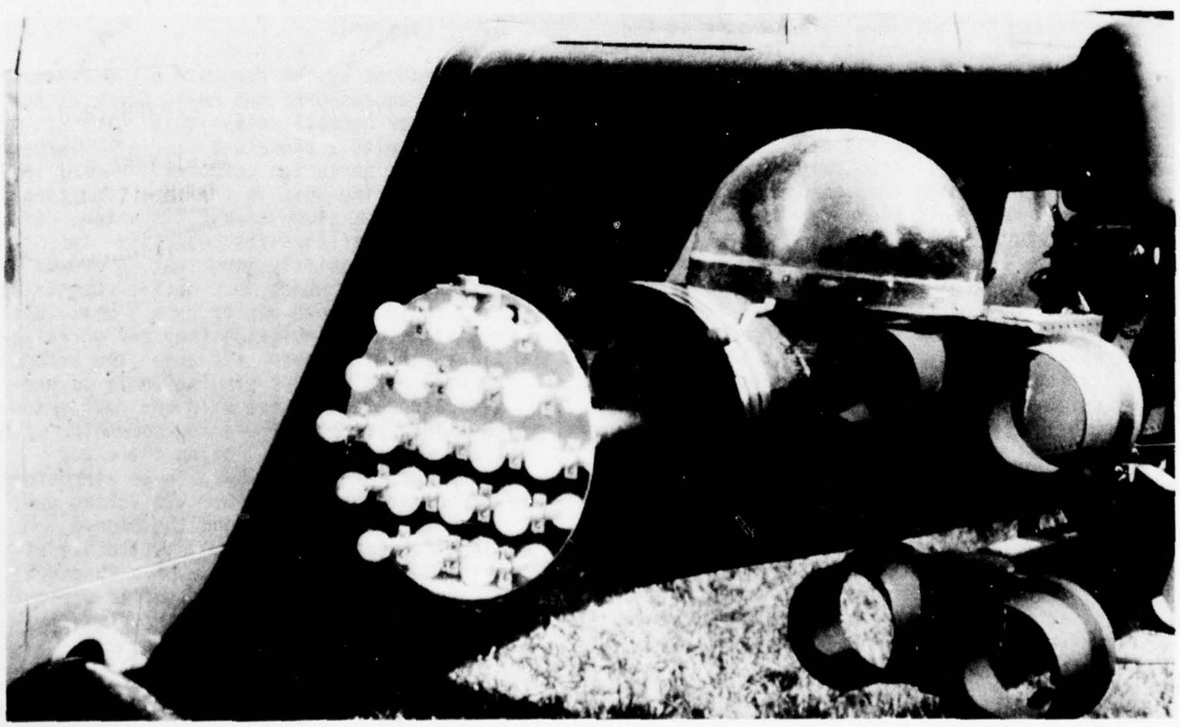

Figure 2. The Signature Simulator for the 2.75 inch Rocket Launcher

The attack helicopters which serve as aggressors are also equipped with signature simulation devices for their three main weapons: 7.62mm minigun, the 2.75-inch rocket launcher and the TOW antitank missile. An example of these simulators is given in Figure 2 which portrays the flashbulb device used in the 2.75-inch rocket launcher pod. These flashbulbs may be ignited by the rocket firing circuit and are visible in excess of 1500 meters if the line of sight is clear.

The key to AGES, as to all engagement simulation, is the control system, which drives the training exercise via administrative control and casualty assessment. The control system consists of a senior controller, who starts the training exercises, supervises exercise play and conducts After Action Reviews; an aviation controller and an air defense controller, who are collocated in the Ground Control Station (GCS); and a controller with each air defense weapon. Using an exercise map with marked locations of ground and airborne weapons systems, the controllers process in the GCS target acquisition information and assess casualties according to probabilistic rules based on capabilities of the firing weapons system and its range to the target. They also identify air defense weapons as being suppressed, which means that firing capability is suspended because they are taking incoming but not lethal fire from "hostile" aircraft. If an air defense artillery (ADA) weapon is assessed as a casualty, the controller at the weapon ignites a smoke grenade providing the aircraft crew with positive feedback for its successful engagement. If an aircraft is assessed as a casualty by the GCS, a smoke grenade is ignited on its skid by radio remote control or the pilot is instructed to pull a tripwire, thus reinforcing the behavior of the air defense crew which did the acquisition and firing. This cueing device is referred to as the hit-kill indicator and is shown in Figure 3.

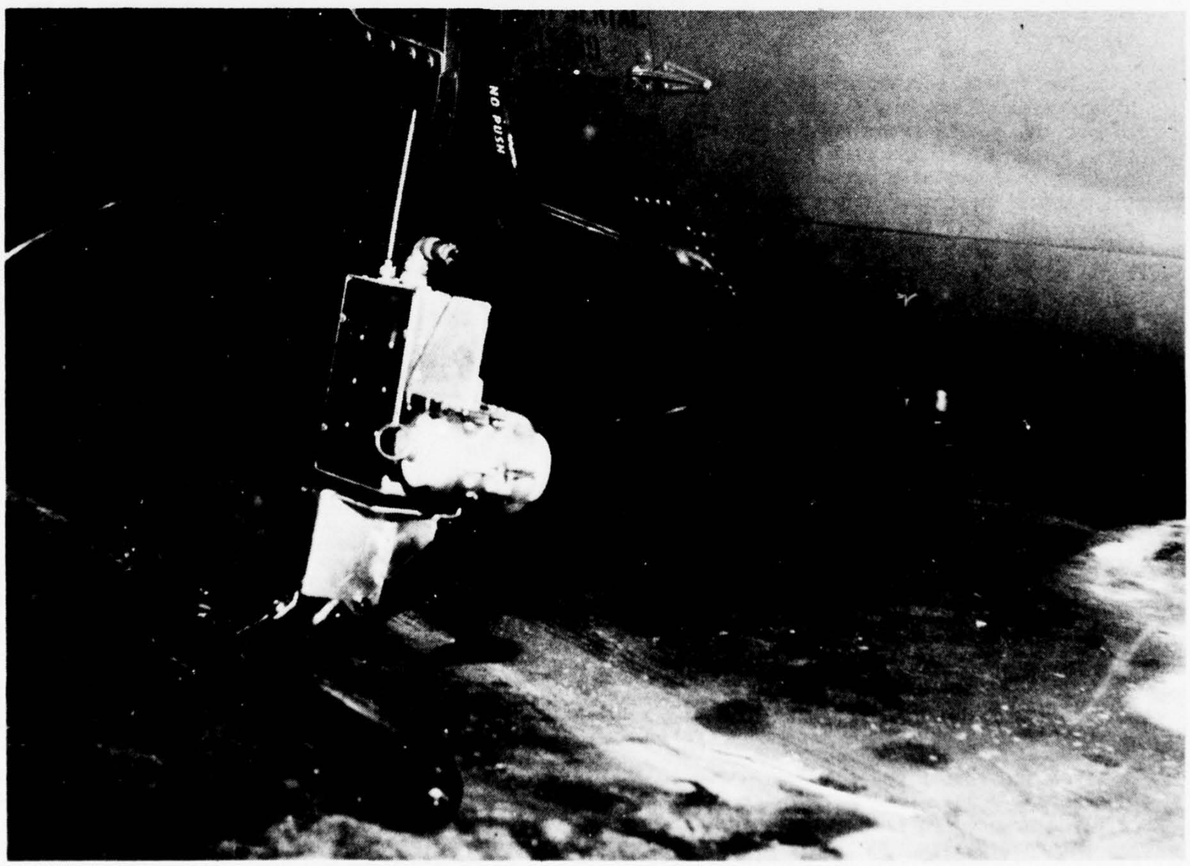

Figure 3. The Aircraft Hit-Kill Indicator

When an AGES exercise is completed, all personnel involved including the control staff and aviators are brought together for an After Action Review (AAR). The purpose of this review is not a traditional critique but rather an exchange of information among those involved. In the AAR, exercise events are reviewed chronologically. The senior controller is trained to act as a discussion facilitator using either a terrain model or a map. Personnel can learn from their own mistakes and vicariously from those who they could not observe directly. Also, positive tactical behaviors are discussed and verbally reinforced.

THE TEST OF AGES IN EUROPE

An empirical test of the AGES concept was accomplished during the summer of 1978 in Europe. Personnel and equipment support was provided by the 8th Infantry Division. The test was run just south of the Lahn River between Koblenz and Frankfurt. The goal of this test was a direct comparison of training effectiveness between AGES and the more traditional field exercise for ADA training.

Two squads of each of the three types of air defense weapons systems were assigned to an AGES training group, and the same number of squads were assigned to a conventional training program. Squad assignment to test conditions was done randomly. The training scenario (missions, orders, terrain) was the same for the two groups. However, the training for the conventional group did not include signature simulation, casualty assessment or After Action Reviews. Personnel accompanying conventional squads served as data collectors performing behavioral observation and data recording with no control-specific duties.

A different set of ADA squads was run through eight exercises each week for two weeks. The aviation aggressors consisted of a pool of approximately ten aviators that remained with the test for its entirety.

METHOD

As with all engagement simulation (ES) exercises, a tactical scenario set the stage for training. The ADA battery commander and the aviation aggressor leader were briefed separately and each was given an operations order. ADA units were told that a large armored force had attacked across an international border, and they were to defend critical assets of the 8th Infantry Division from attack by low and medium altitude aircraft. Air aggressors were ordered to perform reconnaissance in the same general area but were not given any location information on the air defenders. Leaders and subordinates on both sides were allowed to do their own tactical planning and commanding, which provided opportunities for individual initiative. Casualty assessment for the AGES squads was accomplished via the AGES control system. The conventionally trained squads received no casualty assessment, signature simulation, or feedback.

Data collection instruments used in this study included a controller behavioral observation form and rating scales and a leaders'/controllers' questionnaire. Due to the design of the study, more product oriented data such as casualties inflicted by the respective training groups was not possible. Assessing casualties for the conventional group would have confounded the results. However, as will be seen shortly, the process variables employed were able to demonstrate a training effectiveness difference for some weapons systems.

A brief description of the key elements of each of the measuring instruments to be discussed in the results section follows. A Controller Evaluation Form was designed for each of the major air defense weapons systems: Vulcan, Chaparral, and Redeye. Separate forms were required because the job specific behaviors involved with each weapon varied due to employment doctrine and due to the characteristics of the hardware itself. Controllers or behavioral observers were asked to rate performance of weapons crews either on dichotomous yes-no checklists or on nine point semantic differential rating scales. An example of the dichotomous scale is:

Rate local security upon occupation of position.

a. Communication hot loop established? Yes No
b. Ground defense plan established? Yes No

An example of a nine point rating included:

Rate the smoothness of (target) tracking.

Very inadequate 1 2 3 4 5 6 7 8 9 Very Adequate

The controller evaluation forms focused on over 50 specific behaviors associated with proficient tactical performance. Behaviors were drawn from technical manuals and from subject matter experts. Squad and platoon leaders expressed informal opinions that these forms were useful in helping them evaluate crew performance and for use as a training guide.

The Leaders and Controllers Questionnaire was an effort to collect opinion/attitude data from ADA personnel who had been most closely involved in the training. It was administered once at the end of each training week and asked how personnel would prefer to apportion training time across different training techniques to include engagement simulation, live fire exercises, field exercises and battle drills.

RESULTS AND DISCUSSION

Data for the performance of ADA crews drawn from the controller evaluation forms is summarized by producing composite or average summary scores. Data were averaged across the two training weeks so bars in the graph presented in Figures 4, 5 and 6 represent the average ratings for four AGES and four conventionally trained crews respectively.

In Figure 4, the average summary scores for Chaparral crew performance is presented.

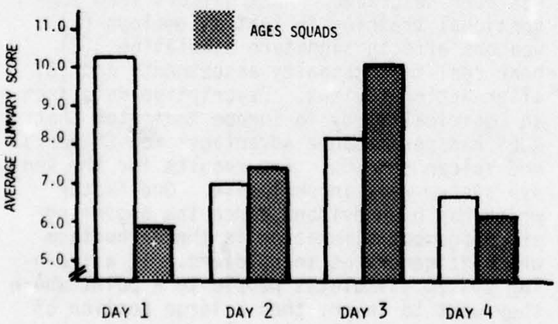

Figure 4
Chaparral Crew Performande Scores

Since the crews were assigned randomly and were not prematched, the divergence on the first day between AGES and non-AGES performance is not surprising. What was surprising, however, was how well the non-AGES crews performed on the first training day as compared to the reaminder of the week. While the AGES crews showed a steady overall improvement through the third day, conventionally trained crew performance declined in the second day and improved slightly in the third, but never reached the first day's level. Both sets of crews showed decreasing tactical performance in the fourth day. This may have been a function of fatigue, crews having been in the field for five days and/or the fact that training ended on Friday afternoons when soldiers were contemplating their weekends. This result was not as pronounced with Vulcan crews and Redeye teams.

As can be seen from Figure 5, the AGES and conventionally trained Vulcan squads began training on the first day with relatively

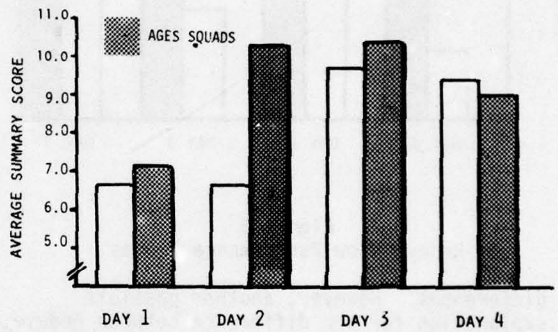

Figure 5
Vulcan Crew Performance Scores

similar performance ratings. Both sets of crews showed improvement from day 1 through the third training day with a slight decrement on the fourth day. It took the conventionally trained crews an extra day of training to reach the level of proficiency of AGES crews. An examination of the crew performance on the two air defense systems discussed so far leads to a hypothesis that the effectiveness of AGES may be system-specific.

Performance of Redeye teams did not follow the same pattern as that of Chaparral and Vulcan crews. The Redeye squads were divergent in initial proficiency from conventionally trained squads based on previous training and/or experience. Figure 6 indicates that AGES squads performed better on the first training day and maintained that advantage over all training days. There appeared to be no difference between AGES and conventionally trained squads in terms of *relative improvement* as compared to the first day's performance. Redeye teams did not retain personnel over the training days in a consistent fashion. This personnel turbulence alone may explain the lack of

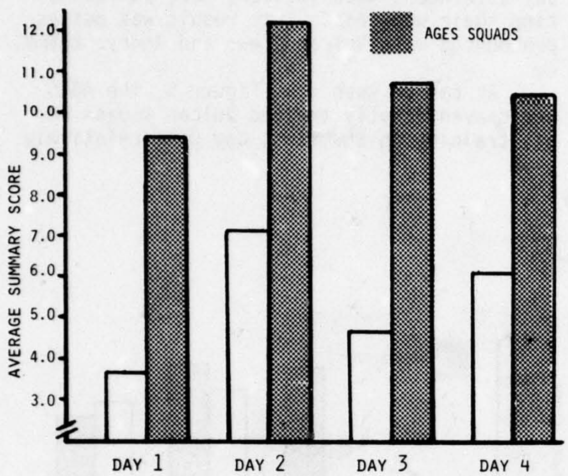

Figure 6
Redeye Crew Performance Scores

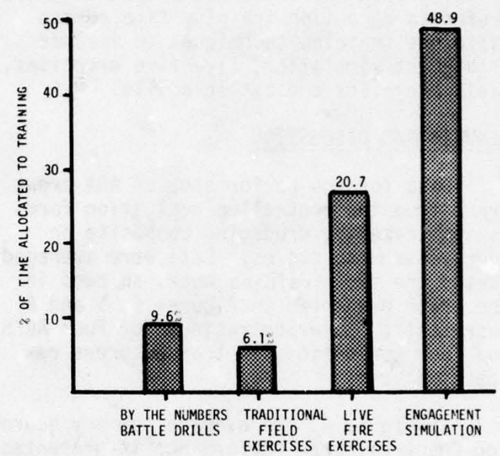

Figure 7. Time Allocated to Training Methods by Participants

differences. However, another possible explanation for the difference between Redeye and the other two weapons systems relates to the sizes of the respective crews and command and control considerations. The Redeye missile is generally crewed by only two men, who are collocated. Communication is simple and straightforward. The crews for Chaparral and Vulcan are more complex, which may complicate coordination. The key to the effectiveness of ES may be in its influence on interpersonal coordination. This again is a speculation which warrants further research.

In the Leaders and Controllers Questionnaire, participants were asked, "If you had a limited time for a training program, how would you divide your time?" Four alternatives were given and the task was to allocate the total time available over the four choices. The results are presented in Figure 7. Fifteen leaders and controllers indicated that they would spend nearly half their available training time using AGES as the principal method. They allocated twice as much time to AGES as they did to live fire and eight times as much time to traditional field exercises. Leaders and controllers were convinced of the value of AGES for training short range air defenders.

SUMMARY

The AGES training system and hardware has been described. AGES differs from conventional training in that it employs (1) weapons effects signature simulation, (2) near real-time casualty assessment, and (3) after action reviews. Descriptive data from an empirical study in Europe indicated that AGES had performance advantages for Chaparral and Vulcan systems. The results for the Redeye system were inconclusive. One factor which has been evident since the beginning of engagement simulation is the enthusiasm which it generates in soldiers. If a training system stimulates people to a point where they want to learn, then a large portion of the training problem is solved.

REFERENCES

Collins, J.J. A study of the potential contributions of small group behavior research to team training technology development. Essex Corp Technical Report, August 1977. (NTIS No. ADA-043911)

Root, R.T. and Erwin, D.E. Engagement Simulation: A training environment for the learning of complex tactical skills. Paper presented at the Military Operations Research Society 38th Symposium, Fort Eustis, Virginia. December 1976.

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NEW DEVELOPMENTS IN NAVY FIRE FIGHTER TRAINERS

Edmund Swiatosz, Wallace N. Guthrie, Jr. and Hubert H. Cadle
Naval Training Equipment Center

I. INTRODUCTION

Shipboard fires represent a constant and pernicious threat to the safety of personnel, the preservation of shipboard equipment and, ultimately, the combat readiness of Naval forces. In response to this threat, the Naval Education and Training Command, through the Naval Training Equipment Center, has initiated experimental development efforts in support of its goal to provide more effective fire fighter training in a pollution free environment. This research and development has provided a viable technical baseline from which to apply the potential of modern technology to this long-standing Navy training problem, a problem compounded by the growing number of restrictions imposed on man's relationship with his environment and the shortage of fossil fuels.

The expedient and effective extinguishment of shipboard fires is directly related to the ability of shipboard personnel to: (1) properly identify and classify fires, (2) communicate the threat, (3) select and properly employ appropriate equipment, and (4) take appropriate offensive action to contain and extinguish the fire without undue risk of personal injury. These behaviors must be instinctive to crew members acting either individually or as members of a shipboard damage control team. The loss of personnel and equipment by fire on board ship is dramatically reduced by a high state of readiness of the crew, a goal which is largely dependent on the effective transfer of training in a realistic fire fighting training environment.

II. NAVY FIRE FIGHTING TRAINING FACILITIES

A. Current Training Deficiency. Fleet fire fighter training schools are currently unable to qualify shipboard fire fighting personnel adequately. Established training goals are not being achieved because training is provided in an environment which lacks the benefit of a modern instructional system. This deficiency is compounded by inadequate numbers of instructor personnel, a growing number of trainees who require fire fighter training at the advanced level, and the lack of capability to present accurately in a training situation the various fire threats which can occur on board ship. Current instruction at the basic and intermediate level is largely limited to the identification of various types of fires, proper handling of fire extinguishing equipment and extinguishment techniques with due consideration for safety, rescue, and other procedural aspects of fire defense. However, practical instruction in combating fires for trainees at the advanced level is generally accomplished using water as the only extinguishing agent. Although this technique provides an opportunity to build self-confidence, the degree of overall skill development is inherently limited. Due to the safety hazards involved, training in some fire situations, such as the deep fat fryer and oil spray, can only be accomplished by demonstration vice participation. Further, various existing simulation facilities are high-rate energy consumers, pollution contributors, and inherently hazardous due to the time lag required to secure the training fire and clear the smoke in emergency situations. Overall, the Navy fire fighting training program as presently constituted provides insufficient hands-on training for adequate skill development at the advanced level and is not consistent with current emphasis on minimizing the introduction of unnecessary pollutants into the atmosphere.

B. Existing Smoke Abatement Process - Shortcomings. In addition to the need to provide more effective fire fighter training, current regulations on air pollution require the development of a non-toxic, non-polluting fire fighter training environment which is consistent with the criteria for clean air as established by the Environmental Protection Agency (EPA) and various state and local ordnances. At present, the Navy's fire fighter training facilities utilize gasoline-impregnated lumber and rubber materials to simulate Class "A" fires and diesel fuel to simulate Class "B" hangar deck and bilge fires. Burning of these fuels results in the emission of large volumes of thick, black smoke particulate along with a multitude of gaseous pollutants.

The current methods used by the Navy to reduce smoke emission from oil-fired trainers are the afterburner and water spray systems. Extensive and costly afterburner systems have been installed in a few fire fighting schools to provide smoke abatement for forecastle, boiler room, engine room and flight deck fire simulators, but are not utilized in open fire trainers. The use of an afterburner results in the effective oxidation of carbon compounds, but the undesirable by-products of this costly process are nitrogen and sulfer oxides. The waterspray method, developed by the Illinois Institute of Technology Research

Institute under contract with the NAVTRAEQUIPCEN, is also installed in some fire fighting schools. Use of the water spray smoke abatement technique effectively removes visible particles from the effluent; however, vast amounts of invisible, toxic by-products of combustion are emitted.

Although both methods effectively reduce visible smoke, neither of these smoke suppressant techniques cleans smoke effectively. In addition, both methods have limited application to training situations which employ open fires and those which utilize liquid foam as a source of extinguishment. Current facilities continue to utilize diesel oil as a primary source of fuel which, in addition to its inherent limitations in performance and safety, will probably fail to meet future restrictions on environmental pollution, even when equipped with an afterburner or water spray system.

C. A Viable Alternative - To identify an alternative to the existing smoke abatement techniques, an exploratory development effort was undertaken by the Naval Training Equipment Center to demonstrate the potential of a new approach to generating fires in a controlled environment using a clean-burning, gaseous fuel in conjunction with a logic control unit and extinguishment agent sensors. This effort consisted of:

- Concept formulation of an array of programmable gas burners which could be utilized for simulating fires.

- Assembly and testing of a digital control unit with a series of multiple burners.

- Study of flame characteristics and the analysis of stack gas under various experimental conditions.

This initial experimental effort demonstrated that, in addition to the advantages of a clean-burning fuel, a system of this type would provide a flexible control capability, including rapid ignition and extinguishment of training fires. Design features to control the rate of fire extinguishment and reflash proved to be feasible and to have potential training applications such as improved monitoring of trainee performance, repeatable training situations, improved safety, and provisions for adaptive type training. In addition, certain cost-effective advantages appeared feasible, such as the repetitive use of foam as an extinguishing agent and the use of foam substitutes.

III. EXPERIMENTAL FIRE FIGHTING SIMULATOR

A. Concept. The concept for an improved fire fighting simulator is shown in block diagram in Figure 1. A training fire would include an array of gas burners and corresponding sensors. As the extinguishing agent is applied to a particular location, it is detected by one or more sensors. Signals from this sensor(s), along with position signals from the motorized gas valves, are fed to a digital control unit. Upon receipt of the proper signal, the digital control unit provides an appropriate delayed signal to operate the necessary fuel valve(s) which controls the flow of gas. Successful extinguishment would depend on the duration of time that the extinguishing agent was applied, the on-off state of the adjacent burner which controls the flame growth and reflash functions, and on the direction provided from the instructor station which also controls extinguishment and reflash.

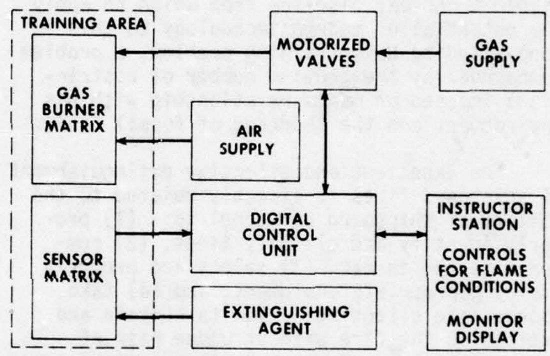

Figure 1. Concept for an Improved Fire Fighting Simulator

B. Control Unit. An experimental digital control unit was designed to demonstrate the system control capabilities. A hard-wired, modular design using digital circuitry for individual standard modules for each burner was used to control fire extinguishment. Any two-burner modules could be interfaced to cause reflash or spreading of the fire. Each module contained a binary counter and necessary logic circuitry to generate the delay time required to accurately simulate extinguishment or reflash. Hence, an appropriate delay time to simulate various types of fires could be obtained by varying the clock rate input to the module counters. It is apparent that the modular character of this experimental concept incorporates sufficient flexibility for adaptation to a variety of different types of control units, such as a programmable controller or microprocessors.

C. Concept Feasibility. To test the feasibility of this concept, several experimental models were configured to generate a controlled propane gas fire from a digitally controlled burner assembly similar to those illustrated in Figure 2. Positive results demonstrated the ability of these experimental

(a) Propane Burner Flames

(b) Foam Extinguishment

Figure 2. Bilge Oil and Oil Spray Simulators

models to generate representative flame characteristics and to simulate flame extinguishment. These factors are considered to be primary sensory cues in a training situation since they will provide valuable feedback to a trainee from which to make decisions. In the course of operating the experimental models, the following additional cues were evident during the various stages of flame extinguishment:

- Even with the fuel valve open, flame height was immediately reduced due to the initial cooling effect of the applied water spray.

- Flames could be extinguished temporarily (gas valve closed) after applying a water spray to the fire for a predetermined time period.

- Reflash of burners occurred when water was not applied in sufficient quantity or over the necessary period of time to cause permanent extinguishment.

- Complete extinguishment of a burner occurred only after application of a sufficient predetermined quantity of water over a specified period of time.

- Reignition of a previously extinguished burner by an adjacent lighted burner would occur unless water was reapplied to both the extinguished burner and adjacent burners.

The realism resulting from the above characteristics was particularly apparent by the initial natural cooling effect of the hose water and by the need to sweep the hose discharge back and forth across the flame area. This action was necessary to prevent reignition of a previously extinguished burner and depended on various combinations of extinguishment and reflash rates from the digital control unit. For example, by appropriate settings of the controls, a variation in the difficulty of extinguishing a fire could be achieved. As this difficulty increased, a corresponding increase in sweep rate of the hose would be required to complete a non-programmed flame response.

The non-programmed response of gas burners using this technique appeared to be particularly suited to the various types of fires which would be required to train a large number of personnel in an advanced fire fighter trainer. This is due mainly to:

1. The inherent advantages of flame control, including rapid ignition and shutdown.

2. The compatibility of the synthetic technique to various types of extinguishing agents.

3. The relative size of small training fires would not require as many sensory cues as larger fires where, for example, larger fires become increasingly more difficult to extinguish the longer they burn.

With respect to Item 2 above, a significant economic advantage appears feasible with this technique when utilizing foam as an extinguishing agent since: (1) permanent extinguishment is accomplished by the logic control unit rather than the extinguishing agent, and (2) the degree of extinguishment realized is independent of the concentation of foam mixtures. Therefore, a training fire to simulate burning oil in a bilge can be repeatedly extinguished with foam without the need for trainer downtime to clean up the residue. In addition, a significant reduction in the concentration of foam is possible. For example, the relatively expensive Ageous Film Forming Foam (AFFF) standard concentrate water mixture could be replaced by a much less expensive synthetic foam. Studies at the Naval Training Equipment Center indicate that a high-expansion foam agent, such as sodium lauryl sulfate in a 10% solution with water, would produce foam characteristics similar to AFFF for less than 10% of the cost of AFFF.

D. Commonality of Models. The experimental model of a bilge oil fire, as shown in Figure 3, used six extended horizontal burner nozzles to position flames within a cavity with the burner controls located outside the flame area. As indicated, the burners were mounted on a bulkhead and flame deflectors were used to spread the flames which would rise upward after leaving the burner nozzle due to their natural buoyancy. The flames then passed through a steel grating which represented a simulated burning surface. A similar design could be used for Class "A" type fires by adding the physical characteristics of non-destructive Class "A" burning materials to simulate a rag bale, wood or mattress. In addition, the appropriate extinguishment characteristics (e.g., delays, reflash, flame size) could be controlled by appropriate settings on the control unit.

The experimental model of an oil spray fire, as shown in Figure 3, used a small horizontal burner to produce a jet of burning gas in addition to the bilge oil burning equipment needed to complete the fire. The propane gas flame having the appropriate gas pressure and air-fuel ratio would appear to emerge from the flanged connections to simulate the characteristics of an oil spray fire. A valve, modified to activate an electrical switch, was used to extinguish the oil spray flame by securing a solenoid control valve on the small burner.

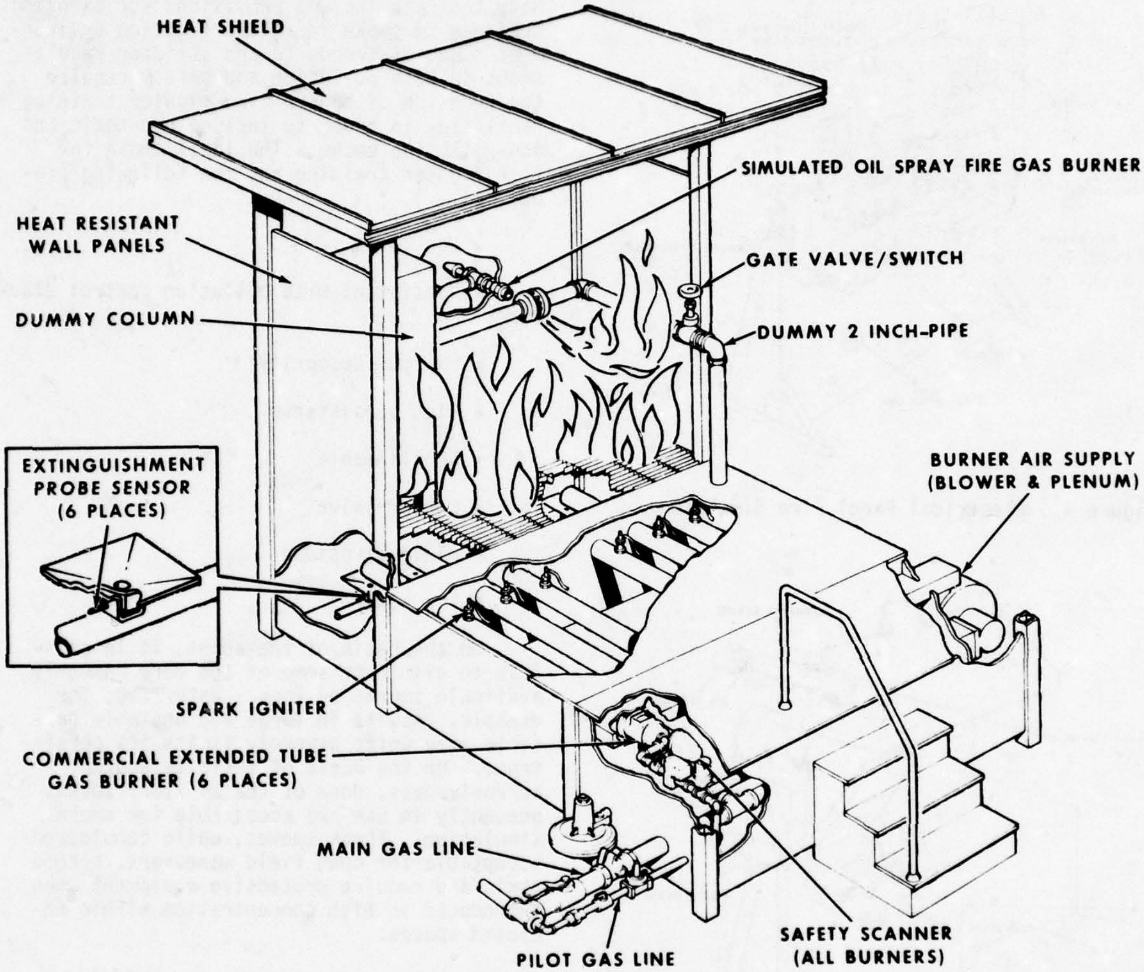

Figure 3. Experimental Fire Fighter Simulator

The experimental model of a Class "C" electrical fire, shown in Figure 4, consisted of two ruggedized electrical control panels and an electrical power panel switchbox. The two panels had provisions for smoke directed from a modified commercial, non-toxic fog oil generator mounted behind a panel representing a simulated bulkhead. The small horizontal gas burner was adjusted to provide a relatively small fire. In this case non-programmed extinguishment control was provided by appropriate electrical circuiting. Extinguishment was accomplished sequentially, first by manually opening the electrical control switch to simulate the securement of electrical power, followed by the application of the appropriate extinghishing agent (PKP or CO_2).

In each of the various models, two basic types of sensors were utilized: flame sensors and extinguishing agent sensors. The flame sensor indirectly sensed PKP or CO_2 extinguishment by detecting the lack of flame when the extinguishing agent was applied. Hence, this type of sensor (i.e., ultraviolet (UV), infrared or flame rod) could be used to monitor for permanent flame shutdown. The extinguishing agent probe-type sensors as shown in Figure 3 and deep fat fryer mockup, Figure 5, are independent of the presence of flame. Therefore, this type of sensor provided the capability for reignition by the control unit and could be utilized to simulate the reflash potential of Class "A" and Class "B" fires.

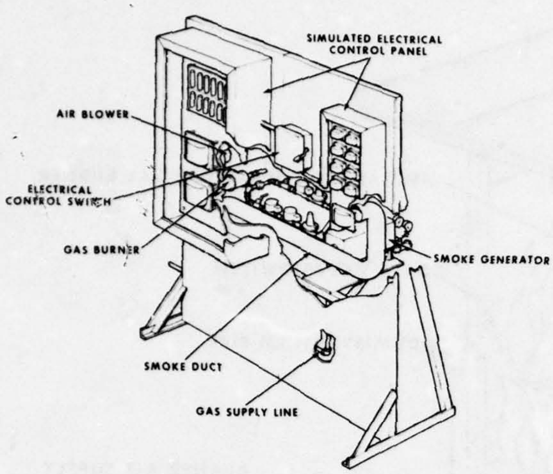

Figure 4. Electrical Panel Fire Simulator

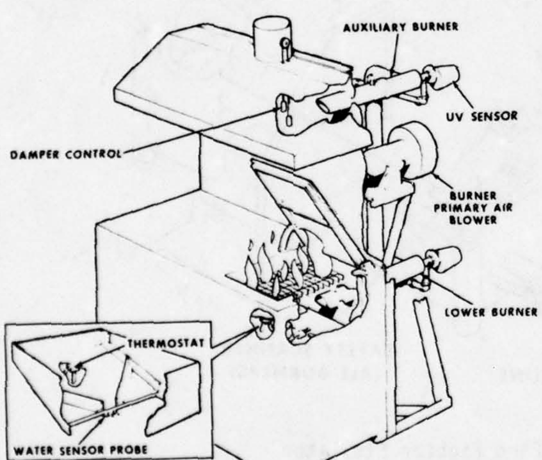

Figure 5. Deep Fat Fryer Fire Simulator

The simplicity of the standard off-the-shelf gas burner equipment was shown to be applicable to the various experimental fires. Also, because of the commonality of both the burner equipment and the basic simulation technique, the experimental units are essentially representative of the more numerous and variety of fires intended for future development of fire fighter trainers. These factors, combined with the flexibility of the digital control unit, provide the potential for a sophisticated and powerful fire fighter training tool.

E. Smoke Simulation. Because smoke is considered to be a highly significant visual cue, Navy trainers include provisions for exposing trainees to smoke in a fire fighting environment. Recent trends toward stricter regulations in both pollution and safety require the redesign of modern fire fighter training facilities in order to include non-toxic and non-polluting smoke. The ideal smoke for fire fighter training has the following properties:

- Non-toxic
- Consistent with pollution control standards
- Maximum obscurity
- High persistance
- Nonflammable
- Noncorrosive
- Minimum residue
- Low cost

On the basis of the above, it is possible to eliminate some of the more commonly available smokes or fogs. Water fog, for example, results in large and unstable particle size which severely limits its persistence. On the basis of toxicity and/or corrosiveness, none of the military smokes presently in use are acceptable for smoke simulation. These smokes, while considered acceptable for open field maneuvers, become toxic and require protective equipment when introduced in high concentration within enclosed spaces.

The absence of a suitable available smoke for use in a training environment, coupled with information derived from other research efforts, have lead to the investigation of various materials known to be non-toxic, such as refined mineral oil, propylene glycol and polyethylene glycol. The condensation of vaporized mineral oil produces an effective and persistent white smoke; however, since it is composed of a mixture of many substances each having a distinct molecular structure, it presents difficult problems from the standpoint of toxic analysis. Moreover, mineral oil fog leaves a distributed residue which could contribute to inhalation problems. While the extent of these problems has not yet been determined, the two glycols are more easily analyzed.

Both propylene glycol and polyethylene glycol are miscible with water and are used as non-toxic food additives. While polyethylene glycol produces a more persistent white smoke than propylene glycol, considerably

more information is available on the latter, particularly on the non-toxic characteristics of its vapors. The lower vaporization temperature of propylene glycol simplifies the design of the smoke generation equipment. Also, preliminary tests with propylene glycol smoke indicate that the smoke can be conveniently controlled for effective obscuration and rapid dissipation. These factors, coupled with its characteristic of minimum residue, make propylene glycol smoke attractive for use in fire fighter training. As a result, propylene glycol has been specified for use in the development of Device 19F1 (Advanced Fire Fighter Trainer - Surface), the first in a series of new generation fire fighter trainers. Studies are currently in progress with the Naval Research Laboratory to investigate possible toxic hazards of the decomposition products from propylene glycol when exposed to a high temperature environment. The results of this effort will determine the need for protective equipment and the acceptability of smoke generation equipment.

IV. TRAINING APPLICATIONS

A. Training Requirement Defined. A training objective exists to develop those psychomotor and team coordination skills required to extinguish successfully fires analogous to those experienced on board ship. The capability is required to simulate, in a controlled environment, a variety of shipboard fires which are perceived by trainees as being realistic as to situation, type of fire, type of extinguishing agent, and available methods for extinguishment. Fires should be confronted under circumstances characteristic of those which exist on board surface ships and submarines with smoke introduced only to the extent required to meet the behavioral objectives desired rather than being endemic to the fire. Training fires are to be capable of rapid ignition, shutdown and restart; and will display the natural characteristics of flare-up, spreading, scattering and reflash if not properly extinguished. Upon completion of a training exercise, rapid removal of extinguishing agents from the trainer is required. Second order influences are required like those in a shipboard fire, such as casual flammables, interference, cascading water, hot decks and bulkheads. Training scenarios must reflect a systems approach to training, designed in such a way that specific training objectives at each event in the training process are clearly identified and properly structured to permit development of increasingly more complex behavioral objectives. Trainee proficiency must be assessable by measurement against standardized criteria. Prior to being trained in advanced fire fighter techniques, trainees will be tested to determine their level of proficiency. Based on their demonstrated entry-level proficiency, they will be sequenced through exercises tailored in such a way as to achieve the requisite advanced learning objectives. Performance goals of the trainee, acting individually or as a member of the fire fighting team, will include proper action to: (1) identify fires, (2) classify fires as to origin, (3) contain fires, (4) extinguish fires, and (5) secure affected spaces without exposure to undue risk of personnel injury.

B. Training Devices Under Development. To meet the Navy's fire fighter training requirements of the future, a new generation of advanced fire fighter trainers is currently under development. These training devices are grouped into two categories: (1) Advanced Fire Fighter Trainers, and (2) a Synthetic Fire Fighter Trainer. Included in the family of Advanced Fire Fighter Trainers are Device 19F1 (Advanced Fire Fighter - Surface) and Device 19F2 (Advanced Fire Fighter Trainer - Subsurface). Both devices are similar in physical configuration and function, differing only in that Device 19F2 includes certain capabilities unique to fighting fires which are indigenous to a submarine environment. For purposes of this paper, Device 19F1 will be described to represent the capabilities and simulation techniques incorporated in both configurations of advanced fire fighter trainers under development.

1. Device 19F1 (Advanced Fire Fighter Trainer - Surface)

a. Physical Structure. The elements of the Surface Advanced Fire Fighter Trainer will function in a structure which houses physical representations of engineering, storage, galley, and berthing spaces of a destroyer type ship. The structure is internally divided into two independent halves. Each half of the structure is further subdivided into two equal portions resulting in a total of four, two story quadrants, each having two compartments. Each quadrant is self-contained to the extent that fire and smoke can be initiated independently in any specific quadrant under the control of the instructor at an instructor's station. The design of the structure will provide for a separate instructor control console for each half of the structure which may be operated independently. Trainee access to the structure will be from roof top hatches. Interior passage between compartments on the same level is provided through doors; passage between upper and lower decks is by vertical ladders. Exterior doors are provided for emergency egress. The physical features of the building and three of the fires included in its interior compartments are generally depicted in Figure 6.

b. Internal Spaces. The interior

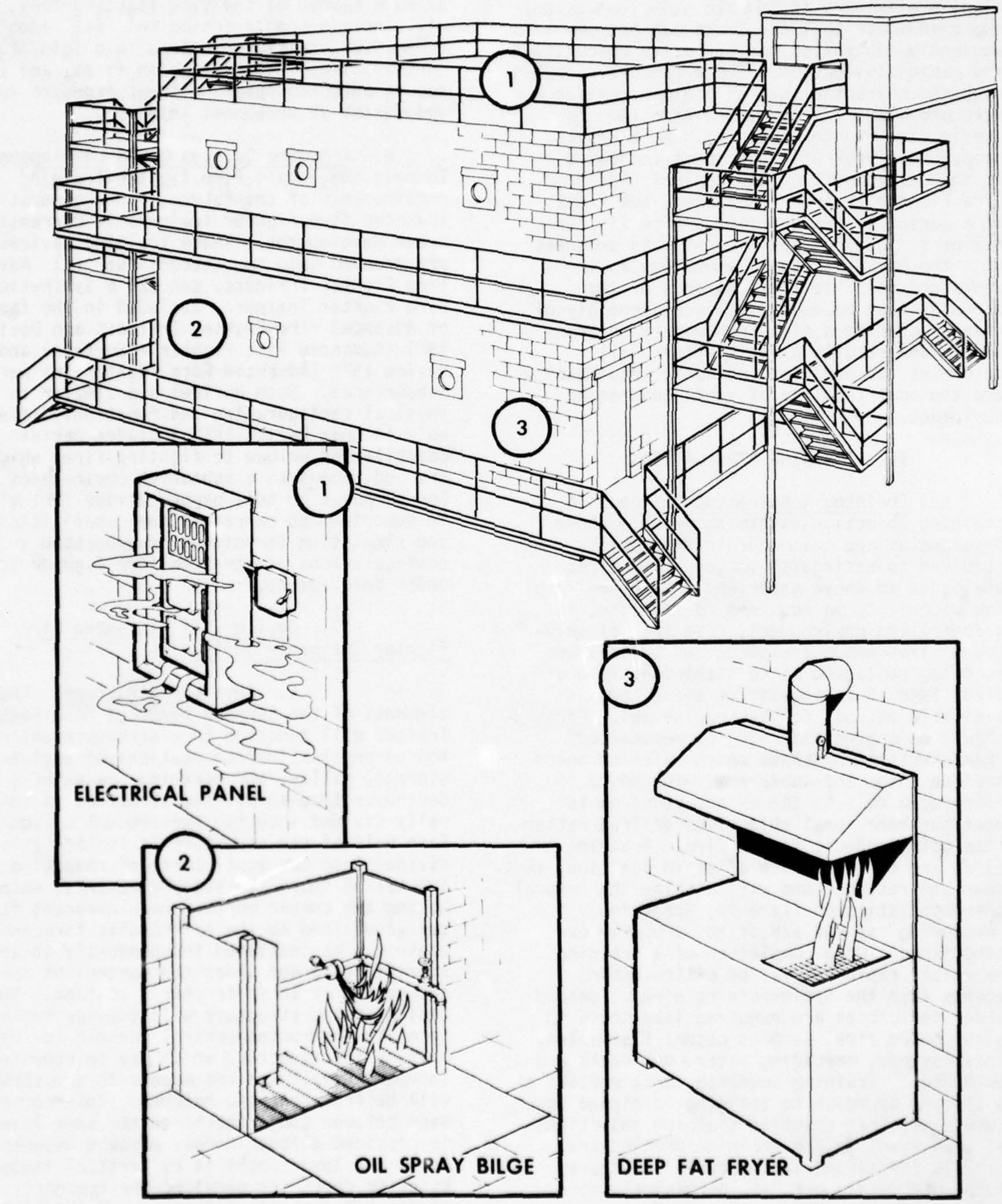

Figure 6. Advanced Fire Fighter Trainer - Surface

of the structure is generally configured to represent compartments on board a surface ship. One half of the trainer will represent berthing storage and galley spaces while the other half will represent engineering and machinery spaces. The compartments will include various non-destructive material and items of equipment typically installed aboard surface ships, including such items as a deep fat fryer in the galley and mattresses in the berthing compartment. This equipment will be designed to provide environmental realism to the extent that it provides physical barriers to visibility and personnel mobility.

c. Fire Simulation. The Advanced Fire Fighter Trainer will include a total of 20 separate fires within the physical bilevel structure, three of which are illustrated in Figure 6. Among these 20 fires will be eight Class "A," five Class "B" and seven Class "C" fires. Five fires will be duplicated and found in multiple locations to provide flexibility in the training scenarios available to the instructor. This redundancy provides the instructor with alternative training situations to reinforce trainee skills in fighting a particular type of fire. Within the training structure, the following number and types of fires will be simulated:

Class "A"	Class "B"	Class "C"
3-Wood/Cardboard Container	2-Bilge	2-Electrical Panels
2-Rag Bales	1-Oil Spray	2-Motor/Generator
1-Mattress	1-Deep Fat Fryer	1-Electronic Equipment
1-Ventilation Duct Work	1-Oil Soaked Logging	1-Electrical Controller
1-Curved Hull		1-Wire Bundle

A design feature of the trainer is to incorporate the following significant characteristics in the generation and extinguishment of fires:

- Flame Growth. Proportionate growth in flame height will occur gradually with time if not contained by the action of the trainee.

- Secondary Fires. Secondary fires and the natural spreading of flames will occur over a variable range of time depending upon the corrective action initiated by the trainee.

- Reignition. All fires, except electrical fires, will reignite if not adequately saturated with the proper extinguishing agent for the time period required. Electrical fires, the deep fat fryer and oil spray fires will continuously reignite if the source of power or fuel is not secured as part of the trainee's corrective action.

- Smoke Generation. Variable quantities of non-toxic, non-polluting smoke may be introduced by the instructor at any time. Where smoke is required as a primary environmental support or cue, as in electrical equipment or containerized fires, it will emanate directly from the simulated equipment.

- Flame Extinguishment. Flames are programmed to be extinguished only if exposed continuously to the appropriate agent over the required period of time. If the proper extinguishing agent is not applied for the required time period, the flames will continue to burn at a reduced height proportionate to exposure to the extinguishing agent.

- Extinguishing Agents. The trainer will include provisions for all types of extinguishing agents currently utilized aboard Navy ships. The installed fire fighting equipment includes representative fire mains, fire fighting hose connections, hoses and couplings, and an all-purpose nozzle and adapter. Fire fighting agents include water, AFFF, twin agent (AFFF and PKP) hoses, portable CO_2, and PKP fire extinguishers.

2. Device 19F3 (Synthetic Fire Fighter Trainer). The Synthetic Fire Fighter Trainer is similar in purpose and design to the Advanced Fire Fighter Trainers. In contrast to the Advanced Fire Fighter Trainers, however, the training situation represented will be a large, uncontrolled bilge fire in an engineering space rather than a large number of smaller fires identifiable to specific shipboard installed equipment. The fire will engulf the entire structure or portions of the structures, and will be extinguished by trainees in the manner prescribed for a large shipboard Class "B" fire. The Synthetic Fire Fighter Trainer will utilize the same technology and techniques for fire generation and control as the Advanced Fire Fighter Trainers. Figure 7 depicts the General configuration of the Synthetic Fire Fighter Trainer.

C. Simulation Techniques. The fire generation techniques employed in both the Advanced and Synthetic Fire Fighter Trainers employ propane gas as fuel which is controlled to burn so as to duplicate the characteristics of Class "A," "B" and "C" combustible fires. These gas fires are extinguished by interrupting the flow of propane gas whenever the proper extinguishing factors are present to activate appropriate electronic sensors which signal a regulating system of control valves in the propane pipe lines. Similarly,

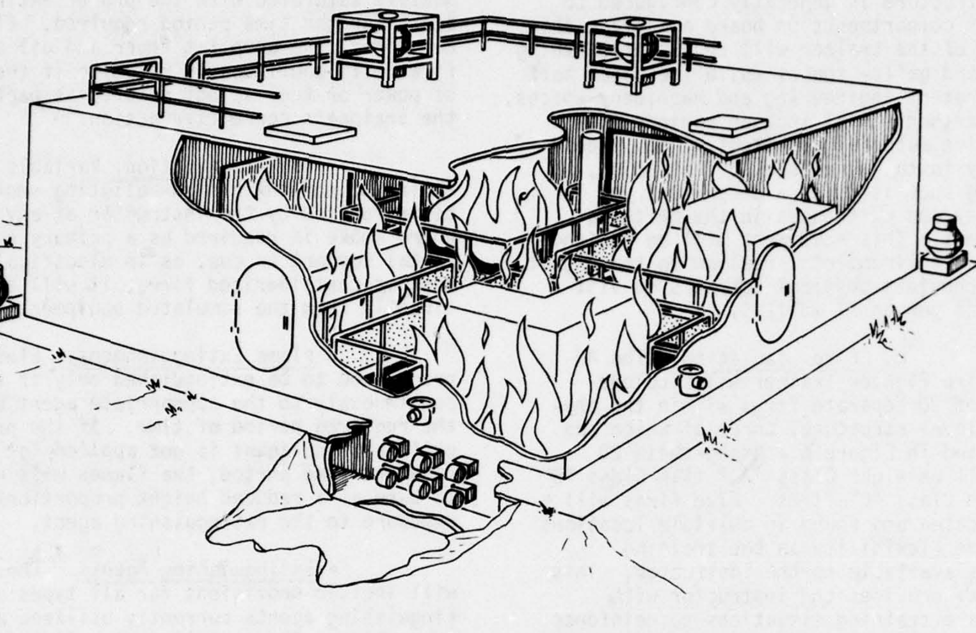

Figure 7. Synthetic Fire Fighter Trainer

anytime improper fire extinguishing techniques are attempted, sensors will respond so as to cause valves to function in a manner which accurately represents the appropriate fire reaction, such as the torching which would result by introducing a stream of water into a fire in a deep fat fryer.

Control of the Advanced Fire Fighter Trainer is exercised from an environmentally controlled, enclosed area on the roof of the fire fighting structure. The control room houses a Square D Company, Class 8881, programmable controller and its peripherals - a control console, a communications console, and appropriate air quality monitors. The propane fires are generated in Maxon gas burners, most of which are located beneath the first and second decks of the outside walkways. Fire tubes beneath the floor grating direct the flames into fireplaces which are configured to simulate shipboard equipment, such as an oil strainer, rag bale, electrical panel, and deep fat fryer. Realism is enhanced by the introduction of non-toxic, non-polluting smoke generated by heating propylene glycol in Steammaster Corporation steam boilers. Smoke will automatically emit from those types of fires which normally generate smoke. In addition, smoke can be added to any compartment on command from the control console to increase the level of difficulty in fire fighting exercises.

D. Safety. Both the Advanced and Synthetic Fire Fighter Trainers will provide effective hands-on training in response to instructor operated, electronically controlled fires in a realistic shipboard environment in which personnel safety is paramount. Personnel safety is achieved by ventilation of the structure prior to the start of training, air quality monitoring, supervised monitoring of the gas burner pilot light, and strategically located switches for emergency shutdown with automatic propane pipeline block and bleed valving. To ensure that Environmental Protection Agency's standards are met with regard to the release of air particulates, effluents from the fire fighting structure are closely monitored.

In fighting fires, personnel are required to employ an Oxygen Breathing Apparatus (OBA). Since the expense of OBA cannisters which generate oxygen is high, an operational OBA has been modified to function like the operational OBA in a gas mask type configuration. Medical approval for use of this modified OBA for training applications is being pursued.

V. CONCLUSION

A. Current Initiatives. Recognizing that a training deficiency exists in the area of fire fighting, the Chief of Naval Operations recently revised Navy policy concerning shipboard damage control training requirements. During CY 1979 the Naval Education and Training Command piloted certain damage control and fire fighting courses which were based upon standardized curricula and represented

a more efficient approach to fulfilling shipboard fire fighting requirements. Also, the Chief of Naval Education and Training currently has under development a comprehensive plan for the future installation of Advanced and Synthetic Fire Fighter Trainers throughout the Naval Education and Training Command over the next ten years. The revised shipboard damage control training requirements, restructured curricula, and the installation of more modern training devices has underscored the need for the Navy to implement a completely new concept utilizing a systems approach to fire fighter training.

B. Program Goal. The overall program goal is to develop within the Navy's training command a modern instructional system which provides both realistic training for personnel on an individual basis as well as advanced training for decision-making members of shipboard damage control/fire fighting teams, such as the on-scene leader, damage control officer and officer of the deck. Recent experimental efforts by the Naval Training Equipment Center have established a sound technical baseline from which to meet the challenge of current and projected fleet training requirements through the application of state-of-the-art technology in trainer design to support development of a total fire fighter training system. This new system will increase the development and transfer of knowledge in the training environment. It will be compatible with pollution requirements and will conserve life-cycle investment and operating expenses. To be sure, problems of fuel conservation and environmental pollution will only intensify in the future. Therefore, an instructional system for future fire fighter training must incorporate in its design the means to minimize the effects of fuel restrictions and atmospheric pollution, while at the same time providing a much greater range of fire fighting situations by which to establish and reinforce trainee self-confidence under controlled conditions.

REFERENCES

1. Hill, T.A., Siedle, A.R., and Roger Perry, Navy Preventive Medicine Unit 2, Norfolk, VA., Hazards of a Fire Fighting Training Environment, American Industrial Hygiene Association Journal, June 1972, p. 423-430.

2. Goldsmith, A. and Wakely, H.G., NAVTRAEQUIPCEN Report 69-C-0181, Fire Simulation Concepts, February 1970.

3. Chapter 9930 Fire Fighting - Ship, Naval Ships Technical Manual, NAVSHIPS 0901-930-0003, December 1976 Edition.

4. Swiatosz, E., Chambers, W., Grimmer, P., NAVTRAEQUIPCEN Technical Report IH-241, Feasibility Demonstration of a Non-Pollutant, Fire Fighting Trainer, December 1974.

5. Swiatosz, E., Grimmer, P., NAVTRAEQUIPCEN Technical Report IH-303, Experimental Research for Advanced Firefighting Simulators, May 1978.

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CIG TRANSLUCENT FACE SIMULATION PROVIDES MULTIPLE BENEFITS

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ABSTRACT

Military training trends are placing increasing emphasis on use of simulators for full-crew, full-mission training. Visual scene simulation must provide effective visual cues with a high degree of realism and a minimum of distracting effects.

The relationships between objects and their shadows, and the changes in these relationships as the observer moves in the gaming area, have been demonstrated to be extremely effective in contributing to the mental correlation process by which an observer extracts knowledge of the world from visual observations. Computer Image Generation (CIG) applied to visual scene simulation has always had the capability to validly portray shadows modeled as part of a fixed environment -- but has had difficulty coping with changing illumination or shadows of moving objects.

The optical laws which apply to transmission of light through translucent faces are quite simple, and it was readily demonstrated that such faces could be used to provide excellent simulation of shadows. This provided the incentive to devise algorithms for such simulation which would be feasible for implementation in real-time hardware.

After the capability to simulate translucent faces was developed, ideas arose for their use in applications other than shadows. They were used for windows, with very realistic results. Overlapping translucent spheres and ellipsoids were used for smoke and cloud simulation. For this application to be satisfactory, the processing must be modified from that process conforming to the laws of physics.

An extremely fruitful use for translucent faces is in implementation of gradual transition between versions of three-dimensional models. This application is expected to be of even greater significance than the use for which they were developed. As in the case of cloud simulation, processing must depart from physical laws for graudal transition -- but in a different manner than for clouds.

In summary, techniques have been developed for simulation of translucent faces. Three modes of operation apply different rules when more than one translucent face is imaged on the same portion of a view window. This allows extended use of the techniques in providing improved CIG effects.

SHADOW CUES

As motivation for the discussion on techniques for simulating shadows, we will first illustrate their effectiveness in providing cues which contribute to proper interpretation of scenes. Figure 1 shows a block sitting on a featureless surface. Figure 2 is the same block, several feet above the ground. Only by knowing the numbers used in the computation could this knowledge be obtained. It cannot be derived from the visual information in the scenes. Figures 3 and 4 show the same scenes, but with the addition of valid shadows. Now the relationship between the block and the ground is immediately obvious.

CIG systems can simulate shadows such as those shown by defining on the ground surface the face or faces representing the shadow. Standard processing then produces the correct portrayal. Where the object or the illumination vector is moving, it is not difficult to dynamically redefine the vertices of the "shadow faces" for valid displays including the movement.

Figure 5 shows a building setting on a pad, with the shadow extending beyond the pad to the background ground surface. To produce this effect with standard CIG systems, we must define faces representing the non-shadowed pad, faces representing the portion of the pad in shadow, and faces defining the shadowed region of the background surface -- each set with the proper computed color or tone. For a stationary data base, this computation is part of the off-line, nonrecurring data base preparation task. With large numbers of objects and shadow-faces in a dynamic simulation, the computational load rapidly becomes intractable. A partial solution has been to make the shadows black, completely obscuring all portions of faces which they cover. This reduces the real-time computational load to that required for situations such as illustrated by Figures 3 and 4 -- but at the expense of a significant reduction in realism. The promise of translucent faces applied to shadows is that a single face could be defined for the

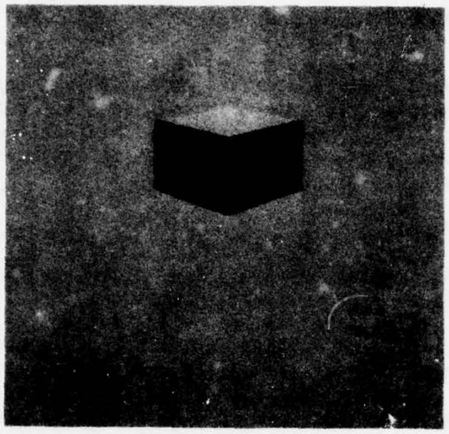

Figure 1. Block on Ground

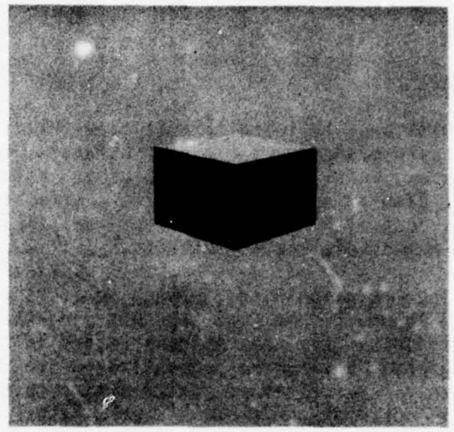

Figure 2. Block Above Ground

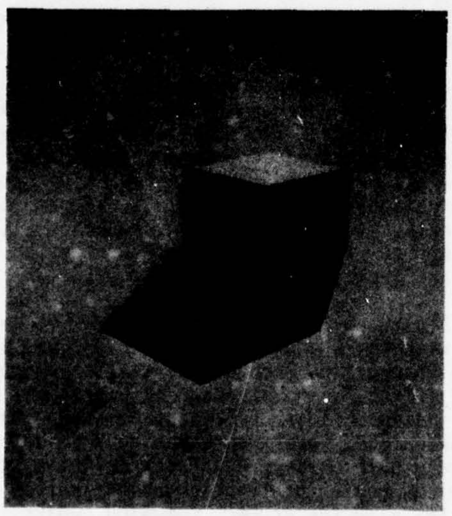

Figure 3. Block on Ground, with Shadow

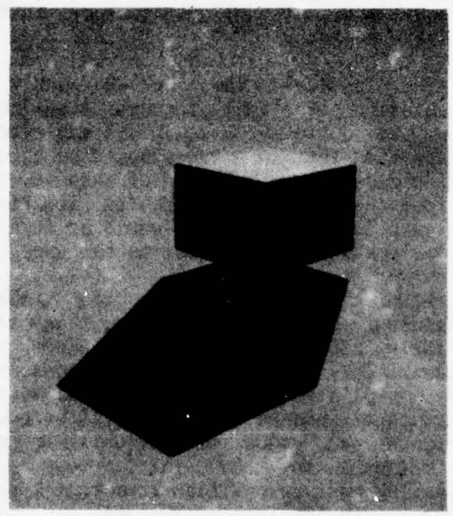

Figure 4. Block Above Ground, with Shadow

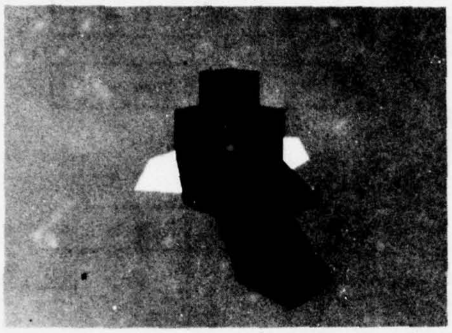

Figure 5. Shadow on Nonuniform Surface

shadow, it could be given color "black," with some defined percent saturation, and all faces and edges covered by the shadow would show through in their correct positions, with realistically modified colors and intensities. The shadow-face computation would be done without regard to what the shadow falls on; yet the result would be fully realistic. Figure 6 is a striking illustration of this realism. It also shows translucent faces used to simulate smoke of variable density.

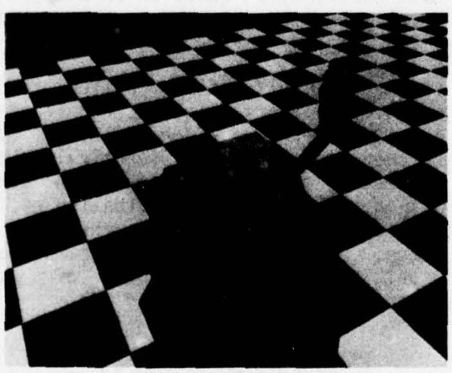

Figure 6. Tank with Shadow and Smoke

TRANSLUCENCE SIMULATION

If we consider a given pixel containing the image of a translucent face with another face (or portions of several other faces) behind it, the processing to determine the proper color for the video applicable to that pixel is quite straightforward. A number of extremely impressive scenes have been produced by applying non-real-time per-pixel processing to simulate translucence. In a typical real-time system, per-pixel time for each channel is 25 nanoseconds, and a number of channels must be processed simultaneously. Thus, for a concept to be feasible for real-time implementation, it must minimize any impact on the per-pixel processing. Ideally it should not impact it at all. The algorithms to be described meet this goal.

Edge Processing

Figure 7 is a partial block diagram showing processing of edges in a CIG system.

The Edge Generator contains information defining edges, circular features, and other entities in their entirety as they appear in the display windows for the current scene. For each scan line, the edge generator determines which edges are "active"; i.e. which appear on the current scan line. It truncates these edges to the top and bottom of the scan line, and outputs them formatted for the current scan line.

The Orderer accepts the set of edge definitions, and orders them in left-to-right order as required for the ultimate scan line video to be generated.

When two or more faces have their images on the same portion of the scan line, the decision as to which is to be shown is made by the next stage, the Priority Resolver. This portion also handles the highly complex and important function of implementing the area-times-color rule to reduce quantization effects.

The Priority Resolver output is routed to the Video Processors -- one for each display channel. These Video Processors combine information from several sources; they implement fog simulation, curvature, and other effects, and output the video to the display devices.

The Priority Resolver and Video Processor functions combined account for the major portion of the hardware in a typical CIG system. Thus, if a new feature can be added in a manner which does not impact these functions, the probability of success will be significantly increased.

Translucence Algorithms

The technique developed for translucent face simulation has the fundamental desirable characteristic defined previously -- it has no effect on any functions of the Priority Resolver or the Video Processor. The added functions take place between the output of the Orderer and the input to the Priority

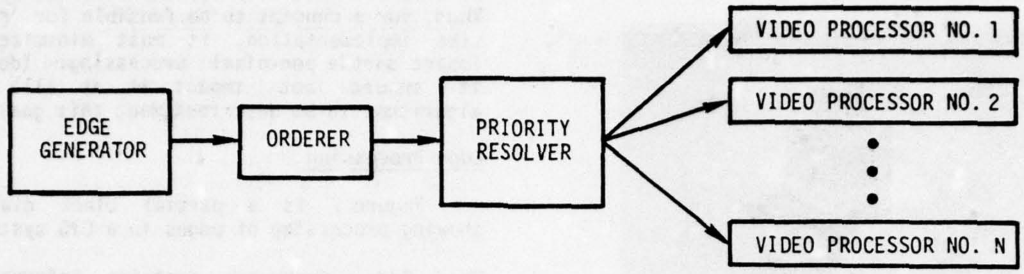

Figure 7. CIG Partial Block Diagram

Resolver. The set of edges from the Orderer is intercepted, modified, and the modified set of edges is then supplied to the Priority Resolver, where standard processing is applied. The result is valid translucent face simulation.

To achieve this goal, two different types of edge modification are required.

Type 1 Edge Modification

In the following, "T" designates tone, or intensity. "0" represents black, "255" is brightest white. "J" has its normal meaning of pixel number along a scan line.

Figure 8 shows part of a scan line. Edge 6 starts face 17, a solid face with a tone of 100 and dT/dJ = 0.5. Edge 7 starts face 4, a translucent face with tone = 20 and dT/dJ = 0. A type 1 modification consists of changing the tone and dT/dJ associated with an edge starting a translucent face. Assume face 4 has saturation of 40 percent. Then the tone associated with edge 7 is changed to (0.4 x 20 + 0.6 x 100) = 68, and dT/dJ is changed to 0.3. In later processing, when the priority resolver encounters edge 7, it will have the values for face 17 seen through face 4. In general, there can be more than one face behind the start edge of a translucent face. The algorithm must use the highest priority face of those behind the edge.

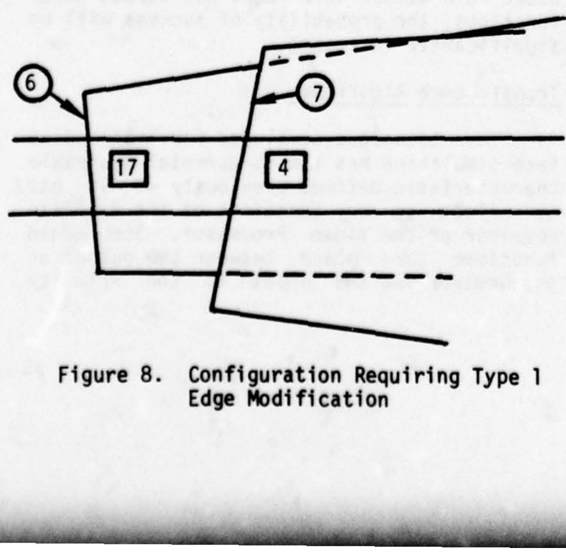

Figure 8. Configuration Requiring Type 1 Edge Modification

Type 2 Edge Modification

In Figure 9, edge 8 starts face 15, which has a tone of 200. At this point, the tone on the scan line must change to 128. However, we cannot just change the tonal information associated with edge 8. Note that at edge 9, we "fall off" the translucent face, and edge 8, with its unchanged original information, will be needed by the Priority Resolver to determine the fallback information. One approach would be to modify edge 9 in this pre-priority-resolver edge modification function, so it would contain the fallback data. Such thinking could make this edge modification function as complex as the Priority Resolver itself -- this we want to avoid.

The type 2 modification, applied to an edge which has a translucent face in front of it, involves creation of an additional edge for the scan line, spatially identical to the edge initiating the modification, with tonal information reflecting the combination of the translucent face and the face to the right of this edge, and with face-left number and face-right number both that of the translucent face.

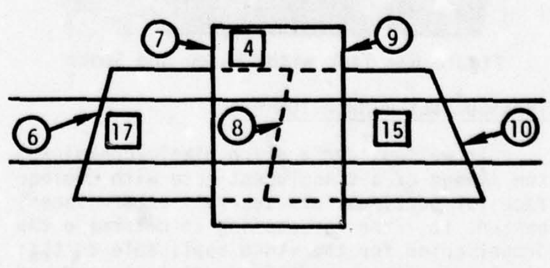

Figure 9. Configuration Requiring Type 2 Edge Modification

Results

Figure 10 shows an algorithm verification test scene. The two vertical

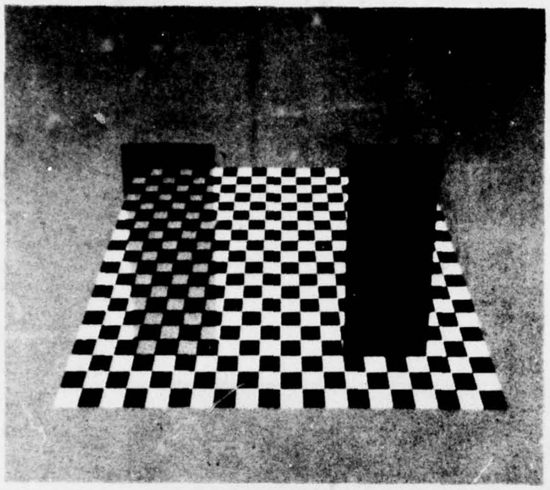

Figure 10. Translucent Face Simulation

faces are assigned the same tone, but different degrees of transparency of saturation. Every combination of edges was validly handled by the algorithm based on the edge-modification concept described.

Figure 11 is a scene more typical of those that might be expected in simulation. Translucent faces are used both for the shadow of the tower, and for the windows.

CLOUDS AND SMOKE

In the simulation of clouds and smoke, it is frequently desired that they be *translucent rather than opaque*, as in previous CIG systems. Highly realistic results have been produced in the past by using overlapping or intersecting spheres and ellipsoids for cloud and smoke simulation. It seems quite straightforward to replace the opaque sphereoids with translucent ones to achieve the desired result.

Overlapping Translucent Faces

Assume we have actual overlapping translucent faces shown as A and B in Figure 12. Assume face A transmits 40 percent of the incident light, and that face B transmits 60 percent. Then the region designated A+B will transmit 24 percent. If there is a bright surface behind the two, the A+B segment will appear as a lens-shaped dark region. This is not incorrect -- it is precisely the appearance we would get with two physical translucent discs. However if we wish to use overlapping spheres to simulate smoke or clouds, we do not want the effect described.

Modification for Cloud Simulation

A simple modification in handling of more than one translucent face on the same portion of a scan line results in the desired effect. For the portion of the scan line where both have images, the processing is as *though* all translucent faces except the one with highest priority have 100 percent transmission. In other cases, such as overlapping windows, it is necessary to simulate true physical translucence. Hence, a type-designation bit is interpreted by the edge-modification logic to determine the type of processing required. The smoke in Figure 6 illustrates the effectiveness of this processing.

GRADUAL LEVEL-OF-DETAIL TRANSITION

Level of Detail

In almost all existing CIG systems, a given feature may be modeled to several levels of detail, with the less-detailed versions requiring fewer edges. When an object is at such a distance that it is very small in the view window, smaller detail could not be seen even if it were computed and displayed, so a lower detail version is used to improve edge utilization efficiency. As the viewer approaches the object, higher detail versions are *substituted* for computation.

There has been one major disadvantage in the use of this technique. The visual perception system is extremety sensitive to abrupt changes in scene detail, even though they are small. Level of detail transitions are thus detected, and can be quite distracting. If the transition from one version to another is continuous and gradual as the exercise proceeds, and the increase in observable detail occurs in a very natural manner, just at it occurs when actually approaching an object, this distraction is eliminated.

Gradual Transition for Two-Dimensional Features

Such gradual transition is quite easy to implement in cases where each face involved has a background of unchanging known characteristics. Consider markings on a runway, for example. Assume marking color is white, and runway color is gray. *During* the period when a given runway stripe is undergoing transition, the entire face representing the stripe will be a constant color for each scene. This is computed as a proportional mix of the face color and the

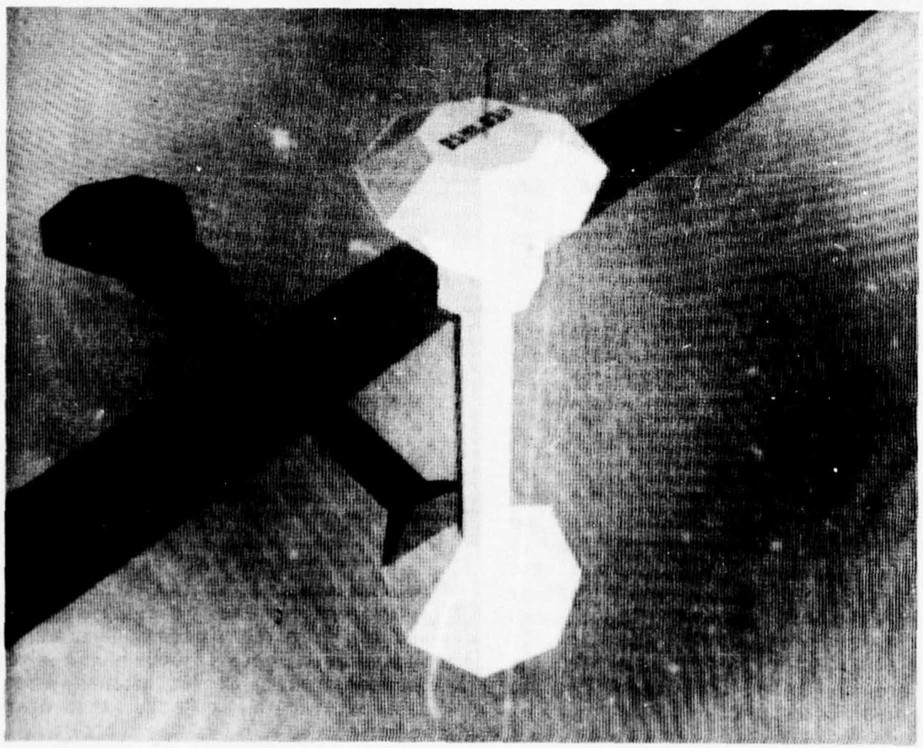

Figure 11. Tower with Shadow and Translucent Windows

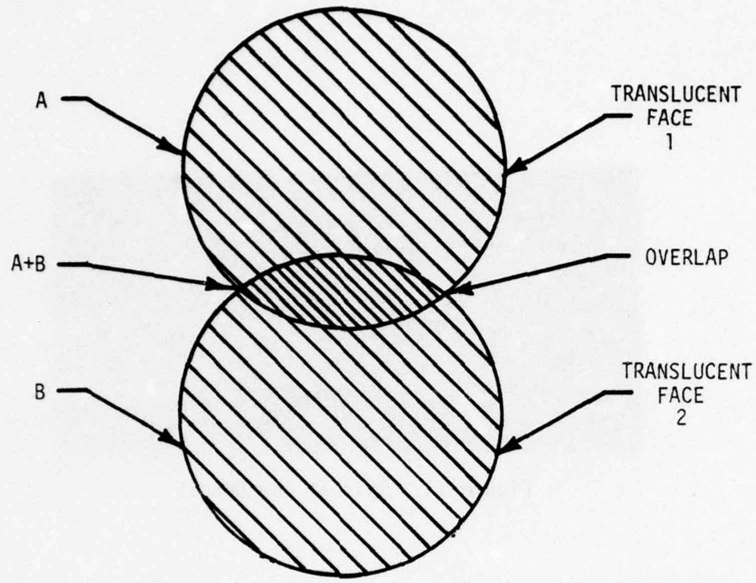

Figure 12. Effect of Translucent Face Overlap

background color, based on position in the transition region. This will change from scene to scene, thus achieving the gradual transition. The proportionality computation can be performed in an early stage of the processing. The modified face color can be computed at the same point in the processing, or the transition factor can be carried along and used later, depending on details of implementation. This capability is present in recent real-time systems, and has proven extremely effective.

3D Gradual Transition

Gradual transition is also required for three-dimensional objects. The above approach is not applicable for such 3-D objects. Not only does the background for such an object vary from scene to scene, it will generally change from one scan line to another, and even when partially through a face on a given scan line. Thus, no scheme of changing a face color applicable to an entire scene can be expected to work.

As part of a study contract for AFPHRL, WPAFB, gradual transition evaluation scenes were produced using a conceptually simple algorithm. The entire scene was generated to both levels of detail involved in the transition. Transition scenes were then produced by combining these two versions proportionally, one pixel at a time. This demonstrated the effectiveness of the transition concept for features with the background changing along a face. This algorithm however, could certainly not be considered a candidate for real-time implementation.

Translucent Faces for 3D Gradual Transition

Consider a point in a mission when a model of a ship is to be in transition between a low level of detail, and the next higher level of detail. Assume we are at the 25 percent point of the transition -- one-quarter of the way from low to high. An approach we might consider is the following. Process both versions of the ship, but designate all faces of the low-detail version as translucent with 25 percent transmission (or 75 percent saturation), and designate all faces of the high-detail version as translucent with 25 percent saturation. Will this achieve the desired goal? Not quite. Even where images from both versions are present (such as the A+B portion of Figure 12), we will see through the ship to whatever is behind it. What is needed here is a third technique for handling multiple translucent faces, in which the saturation is handled in an additive manner. This can readily be implemented by a third mode in the edge modification function following the Orderer.

Figures 13, 14, and 15 show three stages in the transition of a simple model of a ship: low detail, half-transition, and higher detail. These were produced using translucent faces in the mode described. When a video

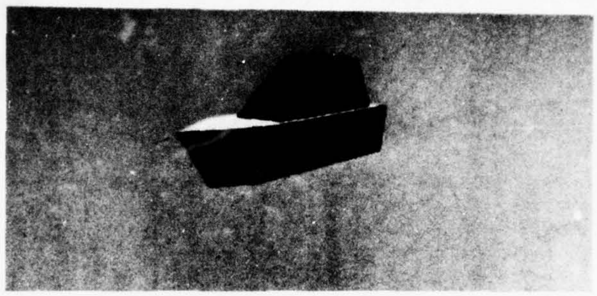

Figure 13. Ship at Low Detail

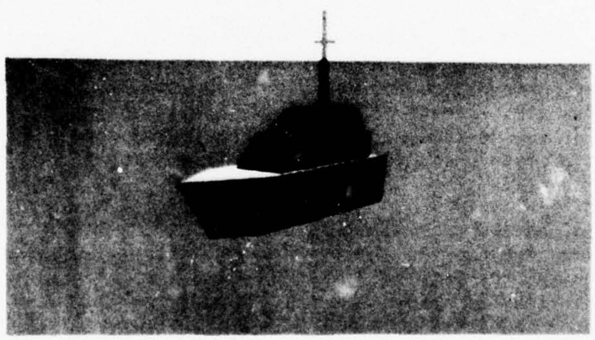

Figure 14. Ship Midway in Transition

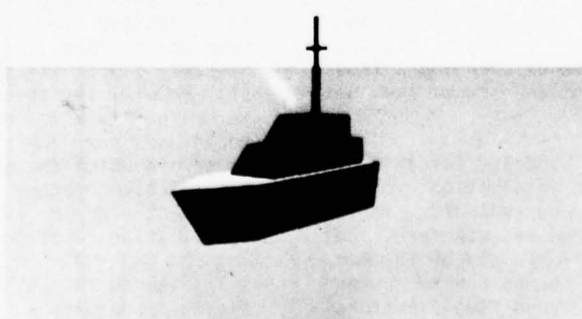

Figure 15. Ship at Higher Detail

tape of this transition is viewed, the effect is very natural and unobtrusive.

Edge Utilization Efficiency

The effect on edge utilization efficiency of simultaneously computing two versions of a model must be considered. As a first comment, even if greater edge capacity is required for a given mission, the elimination of distracting effects could well justify the additional processing. Secondly, assume the transition to higher detail starts at the point where a standard system would abruptly change to the higher detail. The increased edge processing burden would thus be the number of edges in the lower detail version, which will typically be one-fourth to one-half the high-detail edges. Finally, there is a high probability that the natural, nondistracting nature of the gradual transition will mean that level of detail increases can be delayed until the viewer is closer to a model, thus reducing edge processing requirements on a typical scene.

Summarizing the above considerations, it seems highly probable that there will be improved performance with no increase in edge processing capacity required.

CONCLUSION

A technique for simulation of translucent faces has been developed and validated by producing scenes. This approach has characteristics which indicate it should be feasible for efficient real-time hardware implementation. It makes possible realistic simulation of a variety of new features and effects in CIG systems. Probably of even greater importance, it facilitates implementation of gradual level of detail transition for three-dimensional objects, thus increasing realism and adding to edge utilization efficiency.

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COMPUTER-GENERATED TEXTURING TO MODEL REAL-WORLD FEATURES

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ABSTRACT

Current Computer Image Generation (CIG) systems don't provide adequate training effectiveness because they lack the realism to provide pilots with many of the real-world flying cues upon which they have come to depend. This lack of realism is a direct consequence of an oversimplified data base consisting primarily of straight edges. This paper describes an alternative data base developed at the Grumman Aerospace Corporation. The data base avoids edges and uses texturing to model real-world features far more faithfully than conventional CIG systems. The increased realism produces a more valid scene representation and provides the kinds of flying cues encountered in actual flight.

INTRODUCTION

The field of Computer Image Generation has assumed a *dominant* role in providing visual displays for training simulators. Yet, even in its second decade of development, the CIG state of the art fails to meet the requirements of the training community. There are three major shortcomings: failure to provide adequate flying cues, lack of realism, and a data base that is awkward and limiting. Although these three problems are interrelated, each is important enough to warrant separate discussion.

The current CIG state of the art is based on techniques designed to satisfy the limitations of CIG hardware. As a result, we have tended to lose sight of our ultimate goal, training. We have allowed limitations in our equipment -- and our own inventiveness -- to limit training effectiveness. To produce adequate training effectiveness we must produce adequate training cues. NTEC's Jim Burns summed it up when he said that in flight trainers "the name of the game is flying cues" (Ref.1). The edge and flat surface primitives to which current CIG systems are limited do provide training cues, but they are on a gross level -- runway stripes, converging parallel lines and crude polygonal contours. In their inability to cope with the complexity of the real world, these systems have limited their scene representation to a first-order approximation; but real-world features that may be of secondary significance to a machine model may be of primary significance to a human pilot. Gentle terrain undulations, small clumps of vegetation, and even skid marks on runways provide cues that may be essential to prepare pilots for the real world.

It can be seen, then, that the failure to provide adequate training cues is a direct result of failure to provide adequate realism. "Too much realism" has been criticized as a costly indulgence intended more to dazzle the customer than to satisfy his needs. But realism is more than a cosmetic digression. Realism provides faithful training cues, ideally the same cues the pilot will experience in actual flight. In simulation, realism is experience. The more real the simulation, the more valid the experience for preparing the pilot to perform in the real world. The phrase "too much realism," like the phrase "too much money," is a rationalization. It's only bad when you can't get it. There is another aspect of realism that makes it essential to effective training. It can make the difference between a trainee's observing a scene or his being part of the simulation. The motivation generated by current CIG systems was expressed by one pilot: "They're all the same; turn left at the second square mountain." Seeing is not always believing. You must be able to believe in what you see.

Just as the limitation in flying cues is due to limitation in realism, the limitation in realism is due to an oversimplified data base which describes the world as a limited set of discrete, linear features. Significant features of the real world are numerous and seldom even piecewise linear. Furthermore, many natural features, such as trees, clouds, and bodies of water are not well-defined in the sense that their boundaries and shading are extremely irregular. Such features are perceived as complex areas of irregularly shaded patches. It is the overall area that is perceived as significant, not any individual patch, which may have no discernable boundary. Modeling such features with edges gives a sharp boundary to each patch as well as to the area itself. The result is a presentation of too much information -- false information -- to the viewer. This may be interpreted incorrectly as "too much realism" and would account for the confusion in this matter.

It can be seen, then, that dependence on edges is the cause of the training cue, realism, and data base problems. Edges are too costly to represent the complexity of real-world features; and edges are too ex-

plicit to represent nature's subtlety. To solve these problems and provide faithful real-world training cues we must find an alternative data base representation completely independent of edges. Such a representation is provided by texturing.

TEXTURING

Texturing has three basic qualities that make it ideal for modeling real-world features. First, it can be spatially unlimited. A texture function can be defined for the entire scene space, allowing large areas to be modeled by an extremely small data base. Second, it can provide the necessary complexity and irregularity be generating seemingly random patches and blobs. Third, it can mimic nature's subtlety, deliberately avoiding specific boundaries by blending shading from patch to patch.

Texturing is not a new concept; it has been discussed for years. But four basic problems have delayed effective implementation: choosing a texture model, correlating the model with real-world features, assuring perspective validity, and implementing texture generation at real-time display rates.

Three different generic texture models have been suggested. The first uses stored digitized images of real-world features. The problems of data base management and perspective transformation make this approach acceptable only for limited simulation scenarios. At the other end of the spectrum, the second technique involves adding a random signal to the projected image of a scene. Such an approach simplifies high-speed implementation but sacrifices realism, perspective validity, and even frame-to-frame consistency. Between these two extremes lies the third method of texturing, defining a mathematical function that will generate the desired pattern. Such a model can be defined by a small number of parameters to provide a compact data base. The parameters can be selected to correlate with the statistical characteristics of the real-world features being modeled. Perspective validity can be assured by making the scene position coordinates the independent variables of the texture function. Real-time implementation, as with all CIG algorithms, will require special-purpose hardware.

At Grumman, we have developed and implemented such a texturing model. We will demonstrate the model with texturing on a plane, texturing on curved contours, and specially processed texturing. The figures show actual static images generated by a Data General Eclipse minicomputer, stored on a Hughes scan converter and displayed on a Conrac video monitor. The image array is 512 points wide,

Fig. 1. Texturing on a Plane: Terrain

400 points high and has 32 gray-level intensity.

TEXTURING ON A PLANE

Figure 1 shows a ground plane textured to model natural terrain with 23 parameters. Note that the texturing covers the entire plane, representing natural terrain irregularities over an unbounded area. A pilot could fly indefinitely over this simple scene, receiving distance and motion cues throughout his flight.

Figure 2 shows the ground plane textured to model an ocean with 17 parameters. Figure 3 shows a "sky plane" textured to model a cloud layer with 17 parameters. The model parameters can be varied dynamically to produce a rolling sea or drifting clouds.

Note that no objects are defined explicitly in these scenes, yet realistic cues of distance and motion are provided over an infinite area. Simple texturing of this kind suggest the basis for a very inexpensive yet effective part task trainer.

Fig. 2. Texturing on a Plane: Ocean

Fig. 3. Texturing on a Plane: Cloud Layer

TEXTURING ON CURVED CONTOURS

While texturing on a plane gives cues of distance and motion, it doesn't provide realistic cues of spatial contours (Ref. 2). Texturing is a two-dimensional characteristic that can represent area elements on the surface of solid objects in three-dimensional space. It can also suggest small three-dimensional contour irregularities and fluctuations, as in Figures 1 through 3. But it cannot model faithfully three-dimensional objects of significant volume except at great distances (such as high-altitude flight). It is necessary, therefore, to include a capability to model object contours. An important feature of Grumman's CIG system is the modeling of each scene object by a small set of first- and second-order surfaces (Ref. 3). This scheme avoids the limitations of edges and provides a much more compact and manageable data base (Ref. 4).

Figure 4 shows a mountain range modeled by four hyperboloids. Figure 5 shows the same scene with texturing overlaid using a

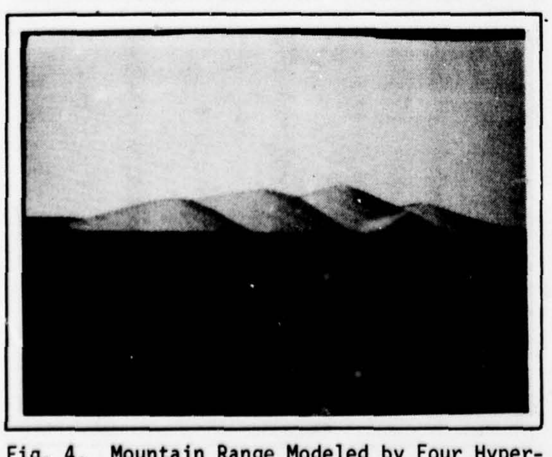

Fig. 4. Mountain Range Modeled by Four Hyperboloids

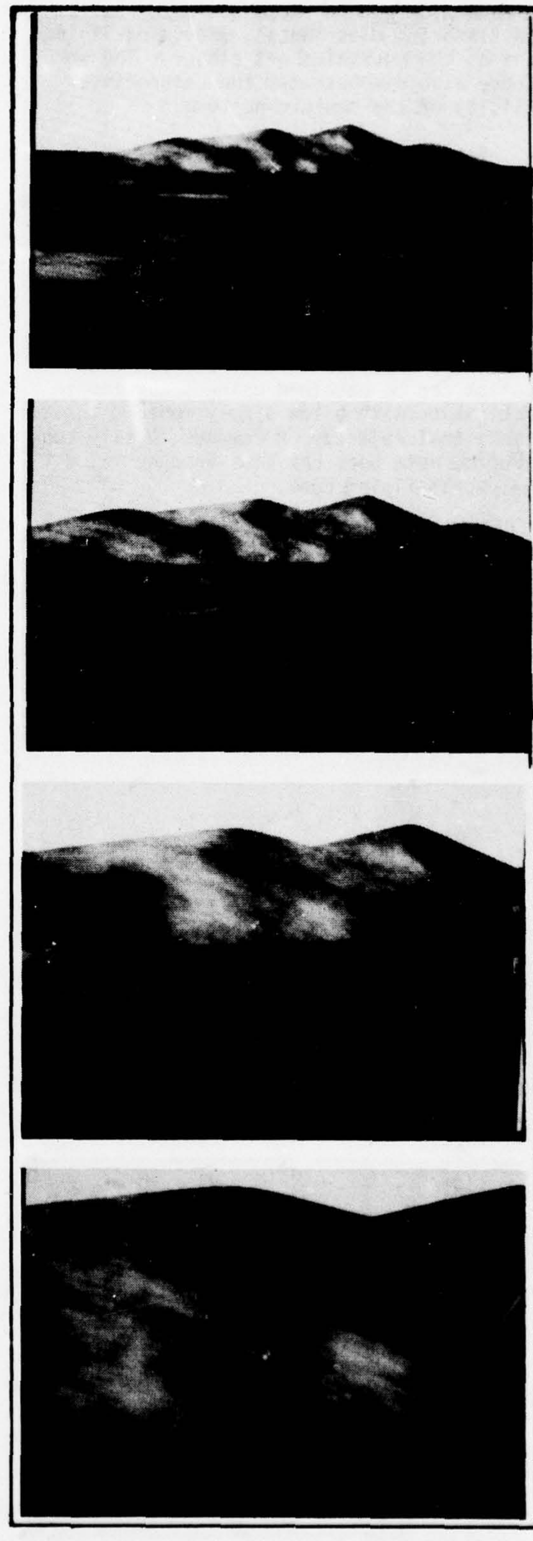

Fig. 5. Mountain Range with Texturing: Approach Sequence

23-parameter model. Note how much realism the texturing contributes, providing flying cues as the mountains get closer. The sequence also demonstrates the perspective validity of the texture pattern.

Figure 6 shows a scene of sand dunes modeled by six hyperboloids. Two hyperboloids are used for each dune to fair the dune into the ground plane and give the effect of rolling terrain. The scene is textured with a 23-parameter model showing the variety of representations obtainable by varying the parameters.

These examples demonstrate how much realism can be obtained using texturing in combination with a few simply modeled three-dimensional objects. A compact, easily constructed data base can thus produce valid real-world flying cues.

SPECIALLY PROCESSED TEXTURING

One of the biggest stumbling blocks to realistic scene modeling has been the complexity of the real world. Nature is always throwing us a curve, and many of the real-world features observed by pilots are so poorly defined that they almost defy computer representation. How do you model a sky full of clouds? How do you model a tree? It is tempting to advocate a compromise on the grounds that such features are not significant enough to merit the cost of faithful replication. After all, clouds and trees are not targets or even objects of interest. But in many aerial missions, clouds can obscure targets, and nap-of-the-earth flight brings helicopter pilots dangerously close to trees. The challenge is not to keep our data base down by compromising on scene validity, but to provide scene validity at a reasonable cost. The texturing model demonstrated above, with some very simple added processing, can meet this challenge.

Figure 7 shows two examples of flight above clouds. Both scenes were generated by the 23-parameter texture model with special processing. The difference in the scenes is due to different choices of parameters. The parameters can be varied dynamically to provide wind speed and direction cues from the drifting and deforming cloud pattern. In addition, an identical but translucent texture pattern can be overlaid on the ground

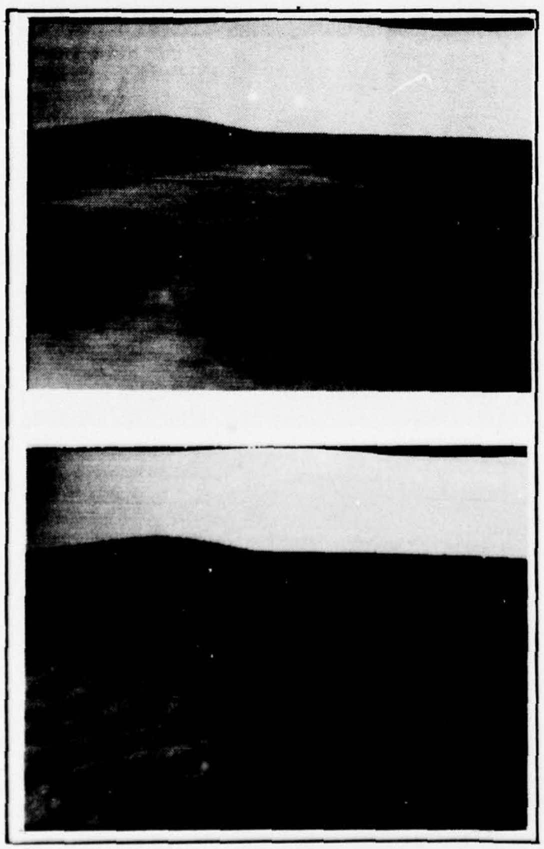

Fig. 6. Sand Dunes

Fig. 7. Clouds Viewed from Above

plane or on any objects below the clouds to simulate the clouds' shadows.

Figure 8 shows four different trees generated by the 17-parameter texture model with special processing. Each tree includes two objects: The upper object is either an ellipsoid or a hyperboloid, and the trunk is a truncated ellipsoid. The figure shows how different types of trees can be modeled by different objects and texture patterns. Figure 9 shows one of the trees close up. Figure 10 shows how more detail can be produced by the addition of two parameters to the model. A sequence of trees can be generated using the same texture pattern so that the data base is kept to a minimum, an important factor in nap-of-the-earth flight where trees "fly" by very fast, presenting a severe data base management problem.

Not all real-world features that provide flying cues are produced by nature; many are man-made. It would seem that these would be easy to model because they generally have an underlying structure. For example, runway lights and markings can be modeled well and with little difficulty. But just as nature can be perverse so can humans, and given all the carefully designed landing lights and lines on a runway, pilots like to use the random skid marks for important landing cues (Ref. 5). Texturing again is the answer. Figure 11 shows a runway with skid marks generated by texturing with a 19-parameter model using special processing.

ADDITIONAL CONSIDERATIONS

The texturing demonstrated here has been implemented as a form of shading modulation. An alternate implementation would be color modulation. This could be used to model patches of vegetation in terrain scenes, markings on targets, lakes in a land scene or islands in a body of water.

An important requirement of any CIG data base is that it be able to utilize the Defense Mapping Agency Aerospace Center (DMAAC) digital source data. Our second order surfaces will provide an efficient means of compressing the data representing the major elevation contour information in the DMAAC data base. Fitting the data will require considerable computation, but it will be done off-line outside the constraints of real-time implementation. The minor elevation fluctuations can be modeled by texturing, with the model parameters being related to the statistical properties of the elevation data.

Another requirement for future simulator systems is the modeling of electro-optical sensors such as infrared. For such sensors the texture model parameters must be correlated with the statistical properties of features as the sensor perceives them.

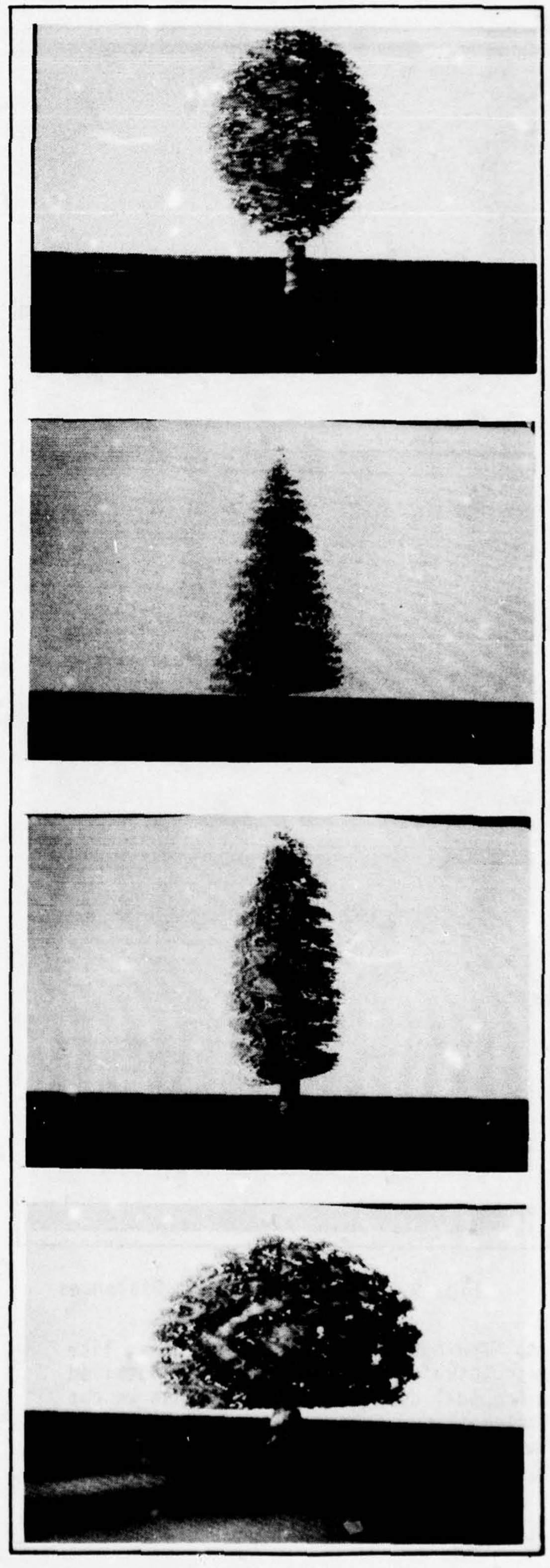

Fig. 8. Trees

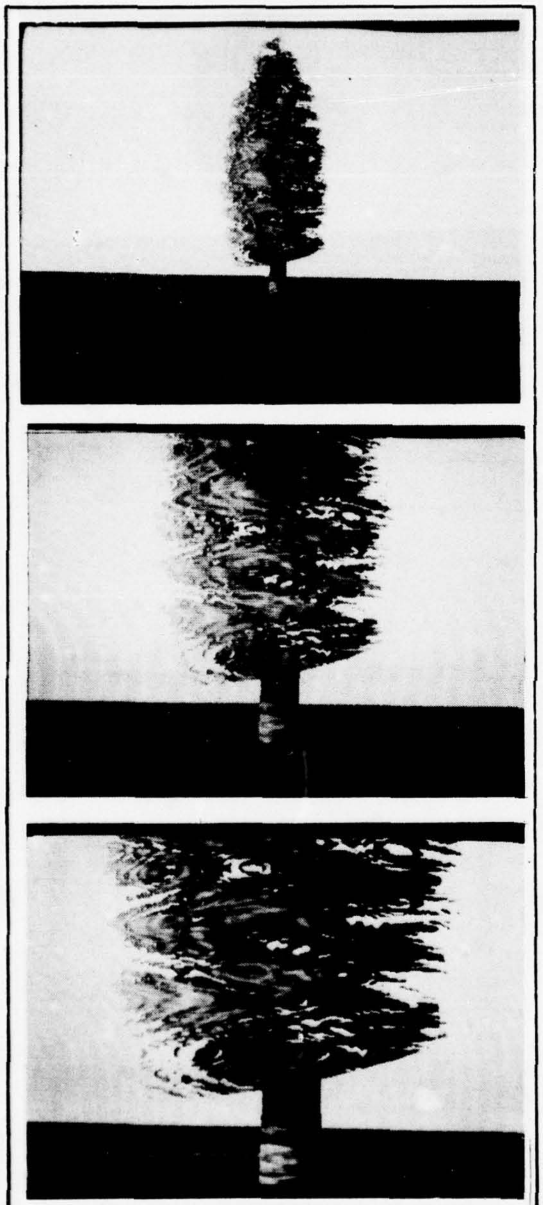

Fig. 9. Tree at Different Distances

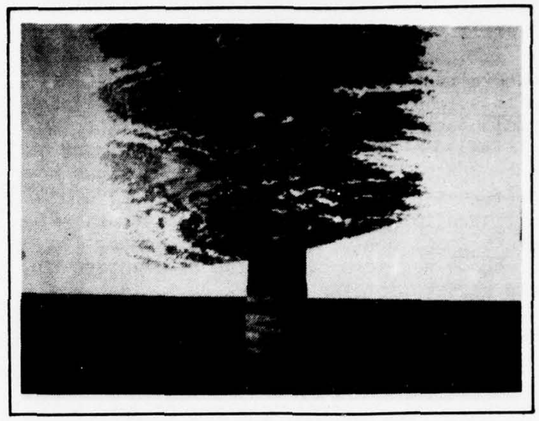

Fig. 10. 10 Tree with Added Detail

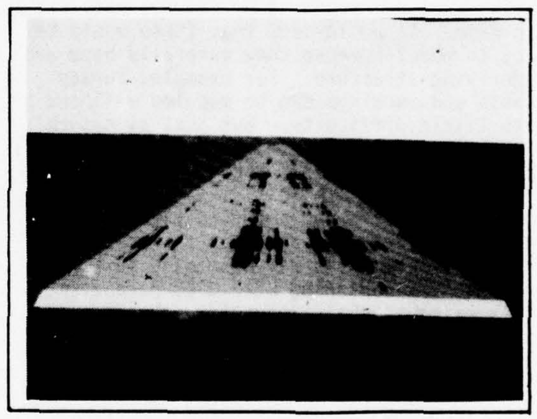

Fig. 11. Skid Marks on Runway

The bottom line on CIG systems, like everything else, is the cost. A detailed conceptual design study shows that we can implement our system with state-of-the-art hardware at a cost well within the range of conventional CIG systems.

SUMMARY

The primary objective of training simulators is to prepare pilots for the real world by providing experience with real-world flying cues. The CIG examples presented here illustrate how the proper data base, firmly rooted in an effective texture model, can provide the necessary realism to produce these cues at a reasonable cost. At this point, the power of texturing seems to be limited only by the imagination and ingenuity of those who use it.

If CIG is to continue to be taken seriously by the training community, it must move out of the penny arcade into the real world. Texturing has opened the door.

REFERENCES

1. Burns, J., "Application of Computer Image Generation to Training at Naval Training Equipment Center," AIAA Working Group on Training Simulation, Daytona Beach, Florida, April 1979.

2. Bunker, W. M., and Ferris, N. E., "Computer Image Generation Imagery Improvement: Circles, Contours, and Texture," AFHRL-TR-77-66, September 1977.

3. Gardner, G. Y., "Computer Image Generation of Curved Objects for Simulator Displays," Eleventh NTEC-Industry Conference Proceedings, Orlando, Florida, November 1978.

4. Gardner, G. Y., "A Computer Image Generation System With Efficient Image Storage," SPIE Technical Symposium East '79, Washington, D. C., April 1979.

5. Buckland, G. H., Monroe, E. G., and Mehrer, K. I., "Simulator Runway Touchdown Zone Visual Requirements; Textural Visual Cue Considerations," Proceedings of the 1977 Image Conference, Williams Air Force Base, Arizona, May 1977.

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REAL-TIME GENERATION AND SMOOTH SHADING OF QUADRIC SURFACES

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INTRODUCTION

In flight simulation it is necessary to portray manmade curved objects, such as water towers, oil storage tanks, bomb craters, silos, other aircrafts, etc. The following describes an algorithm for the efficient generation of curved surface objects in real time; i.e., at thirty frames per second.

Early computer-generated image systems approximated curved surfaces by a number of planar surfaces. The shade across each of these surfaces was constant and was computed by calculating the dot product of the sun's illumination direction with the normalized surface normal. As a result, curved objects look faceted. To eliminate this faceted appearance, Gouraud [1] introduced an algorithm for continuous shading across boundaries of planar surfaces. This algorithm improves the appearance of curved objects but doesn't eliminate completely the faceted effect because the shade gradient is still discontinuous at the boundaries. Another shortcoming is that the silhouette of the object is still composed of straight edges.

Phong [2] introduced an improvement of the smooth shading of the surface, but did not alter the appearance of the silhouette. Because of the complex computation required, no real-time computer-generated image (CGI) systems use the Phong algorithm.

Recently Blinn [3] and Whitted [4] introduced a scanline algorithm for images modelled by bicubic patches. These algorithms have been shown to faithfully represent manmade curved objects. Unfortunately, the computations required are too complex for real-time implementation. An alternative to bicubic patches for curved surface representation are surfaces that can be generated from quadrics. The following describes a real-time algorithm to generate and smooth shade quadric surfaces. Since many types of objects such as buildings and runways consist of planar surfaces in the real world, it is assumed that the ability to process planar surfaces will be retained by computer generated image systems. This capability, however, will be augmented by a method described below to process quadric surfaces. Since the computations required for planar surfaces are well known, our scope will be limited to algorithms required for the processing of quadric surfaces and the merging of planar objects with quadric surfaces.

To minimize the complexity of the processing algorithm, we restrict the class of quadric surfaces to ellipsoids, cylinders, cones and frustrums. we also include planar ellipses in this class even though they are not, strictly speaking, quadric surfaces. More complicated objects can also be modelled by a combination of this class of quadric surfaces together with planar surfaces.

OVERVIEW OF REAL-TIME CGI SYSTEMS

Real-time CGI systems normally generate images at 30 frames per second. Because of this high frame rate, no general purpose computer alone can do the job. Consequently, a real-time CGI system usually consists of a general-purpose minicomputer and a large, special-purpose pipeline processor.

Depending upon the processing algorithm used, the architecture of the special-purpose processor varies among different real-time CGI systems. Most processors, however, can be partitioned into three subsystems, as depicted in Figure 1. The major function of the frame rate processor is to obtain a description of the silhouettes of potentially visible objects in terms of the 2-D screen (image plane) coordinates given their 3-D description in the environment coordinate system. When objects are modelled by planar surfaces, the silhouette description of each potentially visible planar surface is usually in terms of potentially visible "planar-surface edges" defining its boundaries. Each of these edges is characterized by edge parameters which define where the edge starts, ends, its slope, and the shading information of the surface with which the edge is associated. The scanline rate processor takes the description of these silhouettes (planar-surface-edges in cases where the objects are modelled by planar surfaces) from the frame rate processor and generates for each scanline their visible intersections (ordered from left to right, if the scan direction is from left to right). Finally, the picture element rate processor takes the visible intersections together with shading information to their right and generates the shade for every picture element on the scanline.

Regardless of whether the objects are

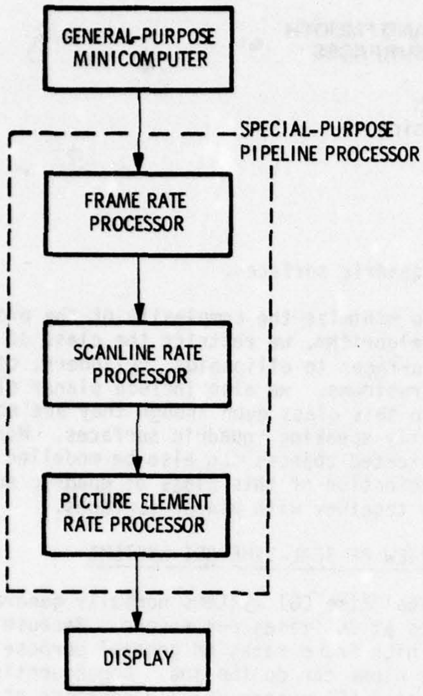

FIGURE 1. ARCHITECTURE OF THE SPECIAL PURPOSE PROCESSOR OF A REAL-TIME CGI SYSTEM

modelled by planar surfaces or by quadric surfaces, the picture element rate processor is the same. However, the frame rate processor is different for these two kinds of modelling because the algorithm to obtain the description of silhouettes is different for each. Also, the scanline rate processor is different for these two kinds of modelling because the algorithm for scanline update of intersections is different for each. Thus, in order to be able to generate objects modelled by planar objects and quadric surfaces simultaneously, two separate parallel processors are required in the frame rate processor and the scanline rate processor.

As stated above, the output of the frame rate processor for planar surfaces is usually in terms of edge parameters of potentially visible "planar-surface edges." In the following sections an algorithm is described which finds the silhouettes of potentially visible quadric surfaces and converts them to potentially visible "quadric-surface-edges." The edge parameters of both types of edges are compatible, thus allowing the same scanline rate processor to be used for both types of edges. With this arrangement, only in the frame rate processor do we have to provide two separate parallel processors, one for planar surfaces and another for quadric surfaces.

ALGORITHMS FOR FINDING SILHOUETTES OF ELLIPSES AND ELLIPSOIDS

As stated above, the quadric surfaces to be handled are planar ellipses, ellipsoids, cylinders, cones and frustrums. Algorithms for generating silhouettes of the last three items are discussed in the next section. Here we are concerned with finding the silhouettes of planar ellipses and ellipsoids. We will show that the silhouettes of planar ellipses and ellipsoids as imaged on the screen are conics and in virtually all cases encountered in flight simulation are ellipses.

For the coordinate systems used, let $\{X_e, Y_e, Z_e\}$ denote coordinates in the environment coordinate system; let $\{X_p, Y_p, Z_p\}$ denote coordinates in the pilot eye coordinate system. The pilot eye coordinate system is such that the origin is at the pilot's eye, the Z_p axis is perpendicular to the image plane. For convenience, let the equation of the image plane be $Z_p = 1$. Thus, the environment and pilot eye coordinate systems are related by an affine transformation determined by the pilot's attitude (pitch, yaw, roll) and position. We define a third coordinate system called the "3-D screen" coordinate system. Let $\{X_s, Y_s, Z_s\}$ denote coordinates in the "3-D screen" coordinate system. The pilot eye coordinate system and the "3-D screen" coordinate system are related by a perspective transformation, one form of which is as follows:

$$X_s = X_p/Z_p \qquad (1)$$

$$Y_s = Y_p/Z_p \qquad (2)$$

$$Z_s = 1/Z_p \qquad (3)$$

Notice that this perspective transformation transforms the image plane equation to $Z_s = 1$ in the "3-D screen" coordinate system. This perspective transformation has the property that perspective projection (with the pilots eye as the vantage point) of objects onto the image plane in the pilot eye coordinate system is equivalent to orthographic (vantage point at infinity) projection of them onto the image plane in the "3-D screen" coordinate system [5]. Therefore, X_s and Y_s coordinates in the "3-D screen" coordinate system are the 2-D screen coordinates on the image plane. Ellipses and ellipsoids can be defined in the environment coordinate system in two forms:

a. Analytic Form in Environment Coordinate System

Ellipsoid: $\left(X_e Y_e Z_e 1\right)[A]\left(X_e Y_e Z_e 1\right)^T=0$ (4)

Ellipse: $\left(X_e Y_e Z_e 1\right)[A]\left(X_e Y_e Z_e 1\right)^T=0$ (5)

$\left(X_e Y_e Z_e 1\right)\left(B_1 B_2 B_3 B_4\right)^T=0$ (6)

where $[A]=\begin{bmatrix} A_1 & 0 & 0 & 0 \\ A_4 & A_2 & 0 & 0 \\ A_5 & A_6 & A_3 & 0 \\ A_7 & A_8 & A_9 & A_{10} \end{bmatrix}$ is a matrix whose ten non-zero elements are the ten coefficients defining the equation of a quadric, and $\left(B_1 B_2 B_3 B_4\right)$ is a vector whose four elements are the coefficients defining the equation of a plane. Notice that in the analytic form, an ellipsoid is defined by ten coefficients while an ellipse, being an intersection of a quadric surface and a plane, is defined by fourteen coefficients.

b. Axes-and-Center Form in Environment Coordinate System

Ellipsoid: $\vec{Q}_1, \vec{Q}_2, \vec{Q}_3, \vec{C}$

Ellipse: $\vec{Q}_1, \vec{Q}_2\ \vec{C}$

where $\vec{Q}_i$ is the i-th "axis" and $\vec{C}$ is the "center."

Given the attitude and position of the pilot, it can be shown that the environment coordinate description of ellipses and ellipsoids in both the analytic and "axes-and-center" forms can be transformed to the pilot eye coordinate description as follows:

a. Analytic Form in Pilot Eye Coordinate System

Ellipsoid

$\left(X_p Y_p Z_p 1\right)[G][A][G]^T\left(X_p Y_p Z_p 1\right)^T=0$ (7)

Ellipse

$\left(X_p Y_p Z_p 1\right)[G][A][G]^T\left(X_p Y_p Z_p 1\right)^T=0$ (8)

$\left(X_p Y_p Z_p 1\right)[G]\left(B_1 B_2 B_3 B_4\right)^T=0$ (9)

Where [G] is a 4 x 4 matrix whose elements are determined by the attitude and position of the pilot.

b. Axes-and-Center Form in Pilot Eye Coordinate System

The pilot eye coordinate "Axes" of both ellipses and ellipsoids are obtained by a rotation of the environment coordinate "Axes." The rotation is determined by the attitude of the pilot. The pilot eye coordinate "centers" of both ellipses and ellipsoids are obtained by translation and rotation of the environment coordinate "centers." The rotation and translation are determined by the attitude and position of the pilot, respectively.

The pilot eye coordinate equation of a tangent cone (or enveloping cone), with the pilot's eye as vertex and tangent to the ellipsoid is obtained from the pilot eye coordinate description (in either the analytic or axes-and-center form) of an ellipsoid (see Fig. 2). Similarly, the pilot eye coordinate equation of a cone with the pilot's eye as vertex and the ellipse as directrix is obtained from the pilot eye coordinate description of an ellipse (see Fig. 3).

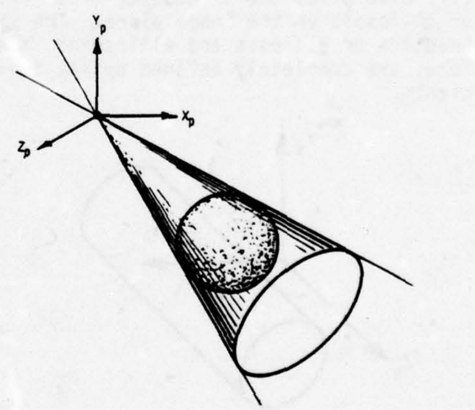

FIGURE 2. TANGENT CONE TO AN ELLIPSOID

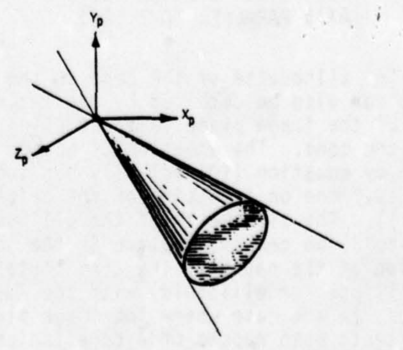

FIGURE 3. TANGENT CONE TO AN ELLIPSE

It can be shown that the pilot eye coordinate equation of a cone whose vertex is at the origin (pilot's eye) is homogeneous in X_p, Y_p and Z_p and of degree two:

$$R_1X_p^2 + R_2Y_p^2 + R_3Z_p^2 + R_4X_pY_p + R_5X_pZ_p + R_6Y_pZ_p = 0 \qquad (10)$$

Dividing the equation by Z_p^2 and using the perspective transformation given by equations (1), (2), and (3), we have:

$$R_1X_s^2 + R_2Y_s^2 + R_4X_sY_s + R_5X_s + R_6Y_s + R_3 = 0 \qquad (11)$$

Notice that equation (11) is free of Z_s terms. This implies that the perspective transformation has transformed the cone defined by equation (10) into a cylinder with axis parallel to the Z_s axis (see Fig. 4). Thus, equation (11) gives the silhouette of the cone on the image plane. Since the cone is a tangent cone to an ellipse or ellipsoid, equation (11) also gives the silhouette of an ellipse or ellipsoid on the image plane. The silhouettes of ellipses and ellipsoids, therefore, are completely defined by six coefficients.

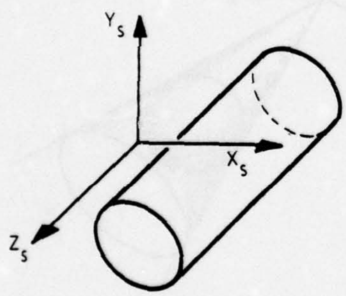

FIGURE 4. CYLINDER WITH AXIS PARALLEL TO Z_s AXIS

The silhouette of the cone on the image plane can also be obtained by the intersection of the image plane (with equation Z_p=1) with the cone. The equation of a cone given by equation (10) actually has two "nappes," one on each side of the origin (see Fig. 5). The silhouette of the ellipse (or ellipsoid) on the image plane is the intersection of the nappe of the cone containing the ellipse (or ellipsoid) with the image plane. In the case where the image plane intersects both nappes of a cone (which rarely occurs in flight simulation), a hyperbola results. One such example is shown in Fig.6. In that figure one side of the hyperbola is real; the other side is imaginary. In most cases, the image plane will intersect only the nappe containing the ellipse or ellipsoid, resulting in an elliptical silhouette. Barring certain situations which rarely occur, the silhouettes of ellipses and ellipsoids on the image plane are ellipses. It will be seen that this property simplifies the generation of "quadric-surface edges" mentioned earlier.

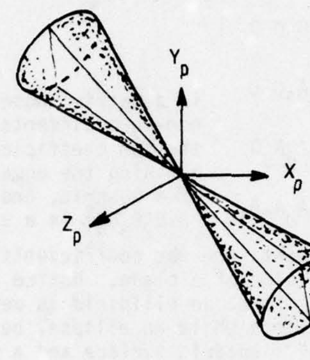

FIGURE 5. TWO "NAPPES" OF A CONE

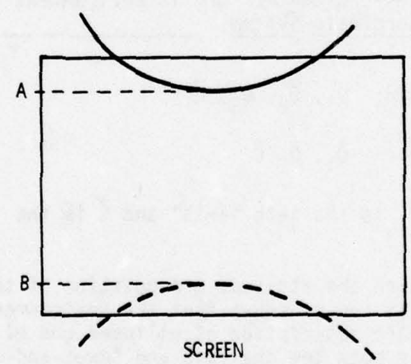

FIGURE 6. HYPERBOLA AS A RESULT OF INTERSECTION OF IMAGE PLANE WITH BOTH NAPPES OF A CONE

ALGORITHM FOR FINDING SILHOUETTES OF CYLINDERS, CONES AND FRUSTRUMS

The silhouettes of cylinders, cones and frustrums consist of one or two ellipses and one planar polygon, provided the vertices of the polygon in the environment coordinate system are redefined dynamically for each pilot position. The algorithm to do this for a general frustrum is depicted in Fig. 7. Let a cone be intersected by two planes, not necessarily parallel, in two conic sections (ellipses in this case). Let the line passing through the pilot's eye, P and the vertex, V (henceforth called Line ℓ), intersect the bottom plane at C and the top plane at F. Let A and B be the two points of contact of tangents from C. Let D and E be the two

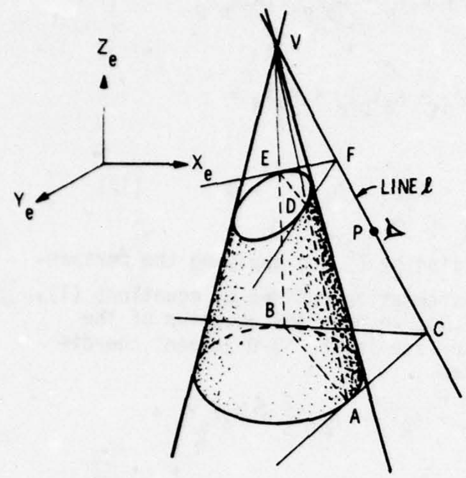

FIGURE 7. ILLUSTRATION OF THE ALGORITHM TO FIND SILHOUETTE OF A GENERAL FRUSTRUM

points of contact of tangents from F. It can be shown that the planar polygon ABED together with the bottom and top ellipse (with appropriate priorities assigned to them) will, when projected on the image plane, give the silhouette of a frustrum formed by the cone bounded by the bottom and top plane. Notice that D and E can also be obtained by the intersection of the top plane with AV and BV, respectively.

There are two special cases to the above theorem:

1. C and F are within the cone. In this case, the polygon surface need not be defined since the two ellipses completely define the silhouette of the frustrum.

2. Line ℓ is parallel to the top and bottom bounding planes. In this case C and F are at infinity, and the points of contact of lines parellel to Line ℓ and tangent to the two ellipses give the vertices of the planar polygon (see Fig. 8).

Cylinders and cones are special cases of a general frustrum. In particular for cones, the planar polygons will be the triangle ABV.

GENERATION OF "QUADRIC-SURFACE EDGES"

To allow the scanline rate processor designed for planar surfaces to also handle quadric surfaces, "quadric-surface-edges" with edge parameters compatible with that of "planar-surface-edges" must be defined. Edge parameters of "planar-surface-edges" are illustrated in Figure 9 for edge AB. The following edge parameters are usually included in real time CGI systems.

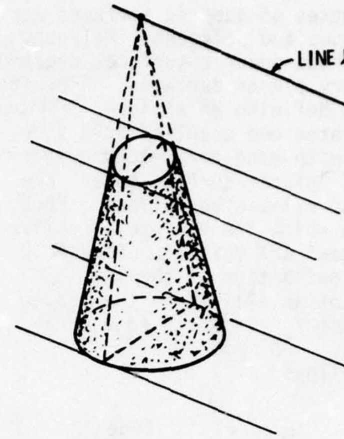

FIGURE 8. HANDLING OF THE CASE WHEN LINE ℓ IS PARALLEL TO THE BOUNDING PLANES

Starting picture element $= X_{S_A}$

Starting scanline $= Y_{S_A}$

Ending scanline $= Y_{S_B}$

Edge slope $= \left(X_{S_B} - X_{S_A}\right) / \left(Y_{S_B} - Y_{S_A}\right)$

Beginning/ending edge flag = Beginning

The edge slope is used by the scanline rate processor for updating the X-intercept of the edge on scanlines on which the edge is active. The beginning/ending edge flag tells whether the surface is to the right or left of the edge. In Figure 9, AB will be designated as a beginning edge while CD will be designated as an ending edge, if the scan direction is from left to right.

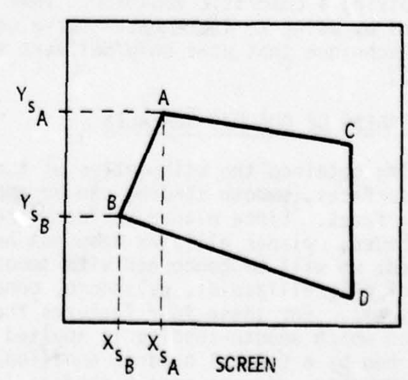

FIGURE 9. ILLUSTRATION OF EDGE PARAMETERS

The silhouettes of quadric surfaces are made up of ellipses and polygons. Polygons generated from these quadric surfaces are processed as ordinary planar surfaces. From the six coefficients defining an ellipse, "ellipse edges" are generated one scanline at a time. "Ellipse edges" with edge parameters compatible with that of "planar-surface-edges" are generated from an ellipse as follows. For each scanline on which the ellipse is active two "ellipse edges" are defined. Figure 10 illustrates the definition of the two "ellipse-edges" of an ellipse on the image plane for scanline $Y_{s_{AB}}$. Their edge parameters are as follows:

	Edge #1	Edge #2
Starting picture element	X_{s_A}	X_{s_B}
Starting scanline	$Y_{s_{AB}}$	$Y_{s_{AB}}$
Ending scanline	$Y_{s_{AB}}$	$Y_{s_{AB}}$
Beginning/ending edge flag	Beginning	Ending
Edge slope	Don't Care	Don't Care

Since starting and ending scanlines are the same, all "ellipse edges" are active on one and only one scanline. Because the silhouettes of quadric surfaces are made up of ellipses and polygons, "quadric-surface-edges" are made up of "ellipse-edges" and "planar-surface-edges." The scanline rate processor will process both types of edges indiscriminately.

The explicit approach to solving for intersections of an ellipse on a scanline requires solving a quadratic equation. This can be avoided by using an incremental curve generation technique that uses only shifters and adders [6].

SMOOTH SHADING OF QUADRIC SURFACES

Having obtained the silhouettes of the quadric surfaces, smooth shading can be applied to the surfaces. Since planar surfaces are not smooth shaded, planar ellipses need not be considered; we will be concerned with smooth shading of only ellipsoids, cylinders, cones and frustrums. For these four features the surface on which smooth-shading is applied can be described by a general quadric equation.* We will therefore discuss smooth shading in terms of a general quadric surface with the following equation in the pilot eye coordinate system.

$$A_1X_p^2 + A_2Y_p^2 + A_3Z_p^2 + A_4X_pY_p +$$

$$A_5X_pZ_p + A_6Y_pZ_p + A_7X_p +$$

$$A_8Y_p + A_9Z_p + A_{10} = 0 \qquad (12)$$

Dividing by Z_p^2 and applying the perspective transformation defined by equations (1), (2), and (3), we have the equation of the quadric surface in the "3-D screen" coordinate system.

$$A_1X_s^2 + A_2Y_s^2 + A_{10}Z_s^2 + A_4X_sY_s +$$

$$A_7X_sZ_s + A_8Y_sZ_s + A_5X_s + A_6Y_s +$$

$$A_9Z_s + A_3 = 0 \qquad (13)$$

Now consider the scanplane given by the equation:

$$Y_s = K \qquad (14)$$

The scanplane (14) intersects the quadric surface (13) in a conic section (ellipse in our case) in X_s and Z_s (see Fig. 11). The far side of the ellipse (i.e., arc ABC) is the

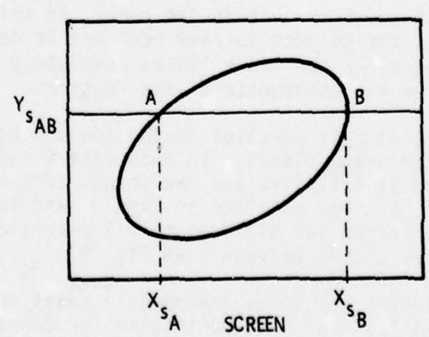

FIGURE 10. DEFINITION OF "ELLIPSE EDGES"

* The top and bottom of frustrums will not receive smooth shading because they are planar.

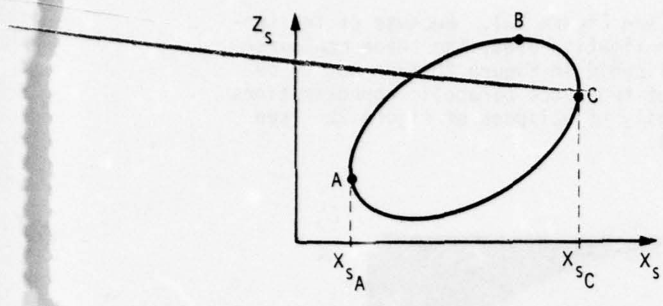

FIGURE 11. INTERSECTION OF QUADRIC SURFACE WITH SCANPLANE

side actually seen because Z_s is the reciprocal of Z_p, the true depth. Consequently, shading along $\left(X_{s_A}, X_{s_C}\right)$ will be determined by the surface normal vectors along arc ABC. Using Phong's illumination model, the surface normal vector has to be computed for each picture element along the segment $\left(X_{s_A}, X_{s_C}\right)$.

This surface normal vector has to be normalized by dividing by the square root of the sum of squares of the three vector components. Finally, the dot product of the normalized surface normal vector with the sun's direction vector gives the diffuse component of Phong's illumination model. The corresponding dot product between the normalized surface normal vector and the direction of maximum highlight vector (defined by Blinn in [7] gives the specular compoent of Phong's model.* Obviously, the above computations are difficult (if not impossible) to perform at the picure element rate. The above exact shading calculation, however, can be approximated closely, but the resulting computations (after approximation) are still difficult to perform at the picture element rate if a brute force approach is used. We will show that an alternative approach to perform the resulting computations drastically reduces the amount of hardware required and at the same time increases the speed at which they can be performed.

The approximation is based on the realization that the components of unnormalized surface normal vectors along the arc ABC are linear in X_s, Y_s and Z_s. This implies that if the arc ABC is a straight line, the components of unnormalized surface normal vectors along $\left(X_{s_A}, X_{s_C}\right)$ can be linearly interpolated.

* For shading calculation, the surface normal vector, the sun's direction vector, and the direction of maximum highlight must be expressed in the same coordinate system. The coordinate system should be one before the perspective transformation, i.e. either environment or pilot eye coordinate system.

Unfortunately, arc ABC is not a straight line, yet a reasonable approximation to the arc is a piecewise linear approximation. If this is done, the components of the unnormalized surface normal vectors along $\left(X_{s_A}, X_{s_C}\right)$ can be piecewise linearly interpolated. This reduces the smooth shading problem of quadric surfaces to one similar to the smooth shading of planar surfaces addressed by Phong [2], which linearly interpolate the components of unnormalized surface normal vectors from surface normal vectors at the vertices of planar surfaces.

Let us focus on one piece of the piecewise linear approximation of arc ABC. Since the components of unnormalized surface normals are linearly interpolated, it can be shown that the unnormalized shade (the dot product of the unnormalized surface normal vector with the Sun's direction vector and direction of maximum highlight vector for the diffuse and specular components, respectively) can be obtained by a simple linear interpolation. In order to obtain the normalized shade, it is necessary to divide the unnormalized shade by the length (norm) of the unnormalized surface normal vector. It can be shown that the norm squared of linearly interpolated unnormalized surface normal vectors can be expressed as a recursive relationship, thus enabling them to be incrementally generated. To obtain the normalized shade therefore, the linearly interpolated unnormalized shade is simply divided by the incrementally generated surface normal vector length.

EXPERIMENTAL RESULT

The algorithms discussed above have been implemented in a non-real-time CGI system. Figures 12 to 17 depict some of the quadric surfaces generated without smooth shading. The effect of smooth shading is illustrated in Figures 18 to 23. Only the diffuse component is used in these illustrations, although the specular component can easily be added. The shading model used is:

$$\text{Shade} = A + (\vec{N} \cdot \vec{S})$$

where A = Ambient light

$\vec{N}$ = Normalized surface normal

$\vec{S}$ = Sun's direction vector

Unless otherwise stated, the smooth shading scheme discussed above (with a two-piece approximation) is used. Figure 18 shows a partially smooth shaded ellipsoid (the right half is painted uniformly). Note that the half which is not smooth shaded looks two-dimensional. Figure 19 shows an ellipsoid without smooth shading. A completely smooth shaded ellipsoid is shown in Figure 20. For comparison, another ellipsoid is smooth shaded with exact calculation of normals. This is shown in Figure 21. Comparison of Figure 20 to Figure 21

shows that the approximation scheme doesn't perceptibly degrade the shading quality. It is also interesting to compare the shade (intensity) contours of the ellipsoid in Figures 20 and 21. As expected, shade contours of the ellipsoid in Figure 21 are a family of ellipses (see Figure 22). Because of the two-piece approximation used, the shade contours of the ellipsoid in Figure 20 turn out to be a family of two-piece parabolic approximations to the family of ellipses of Figure 22 (see Figure 23).

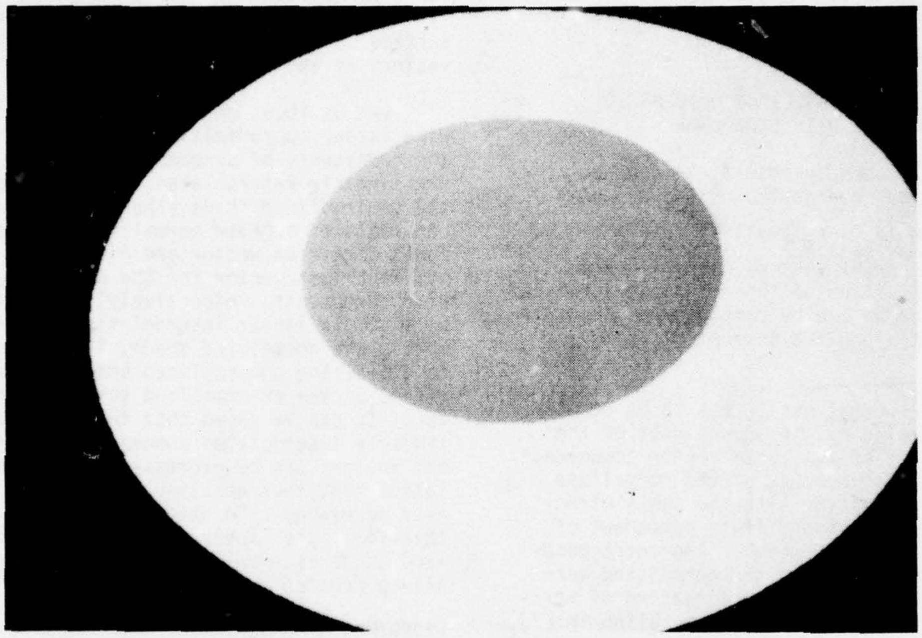

FIGURE 12. PLANAR ELLIPES ON THE GROUND

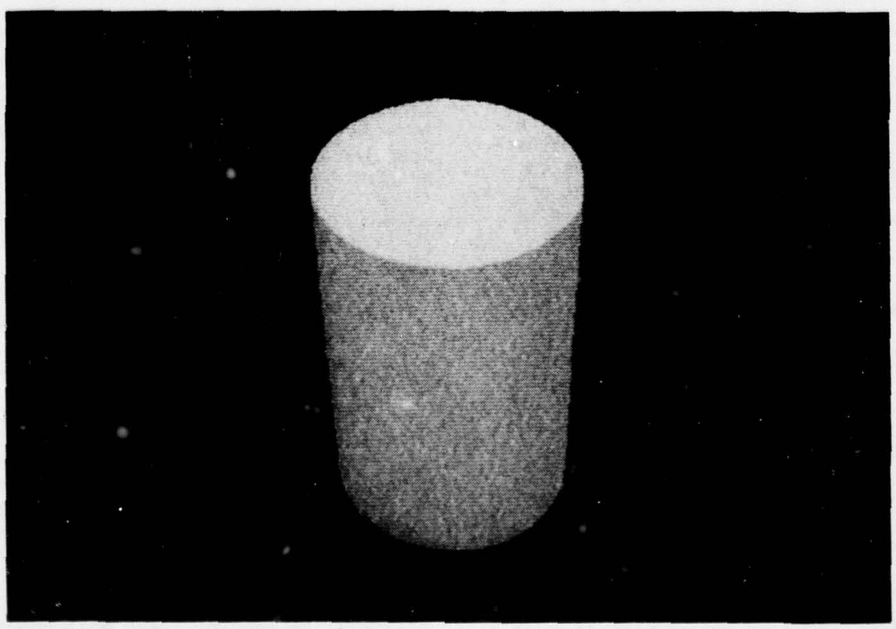

FIGURE 13. A RIGHT CYLINDER

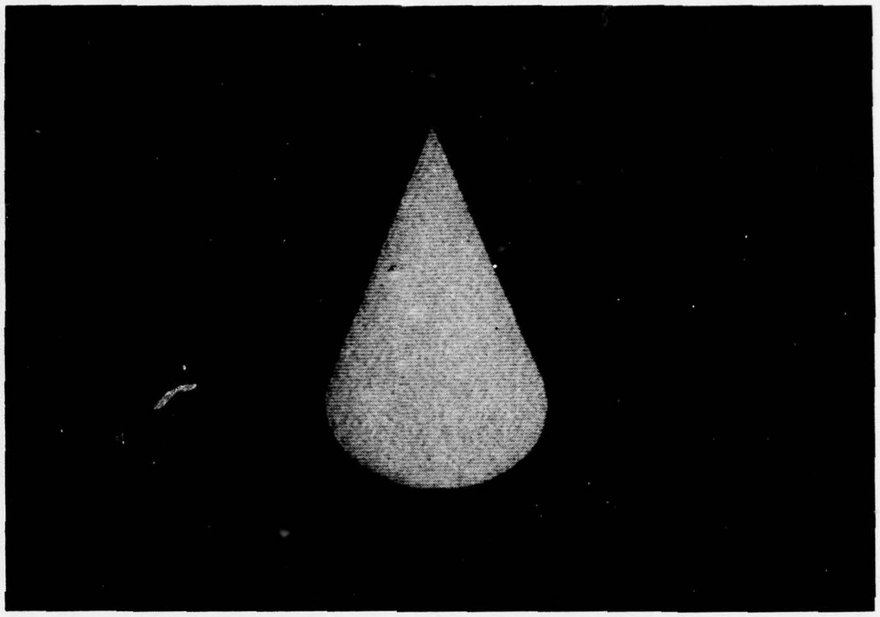

FIGURE 14. A RIGHT CONE

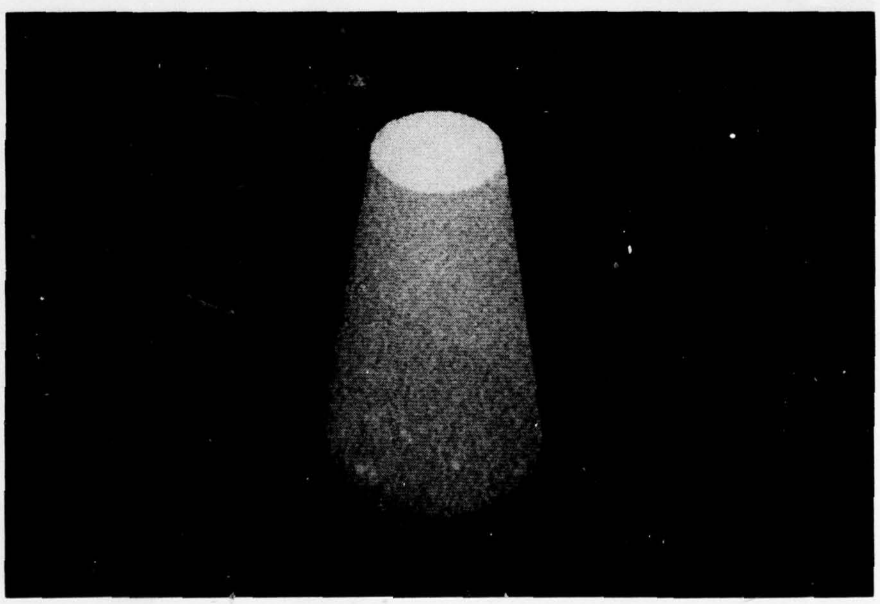

FIGURE 15. A RIGHT FRUSTRUM

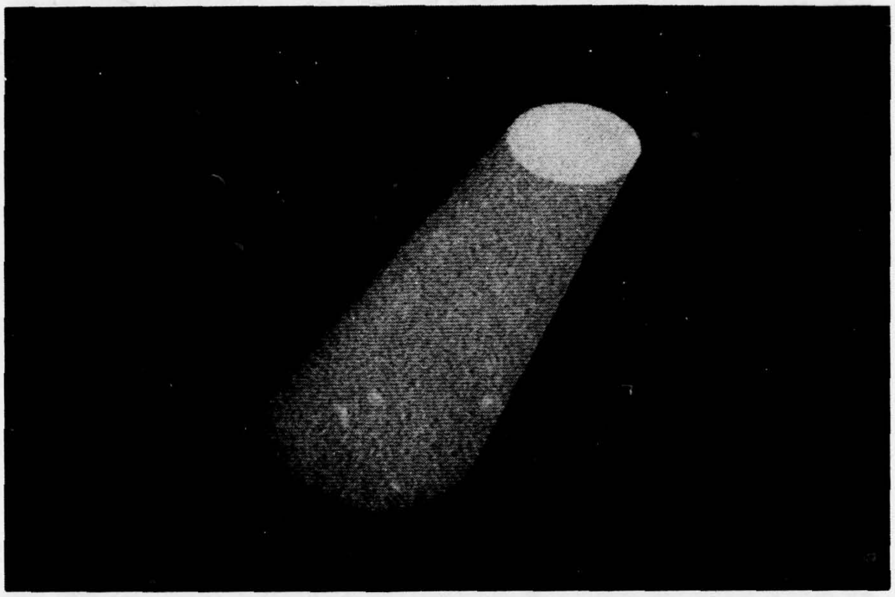

FIGURE 16. AN OBLIQUE FRUSTRUM

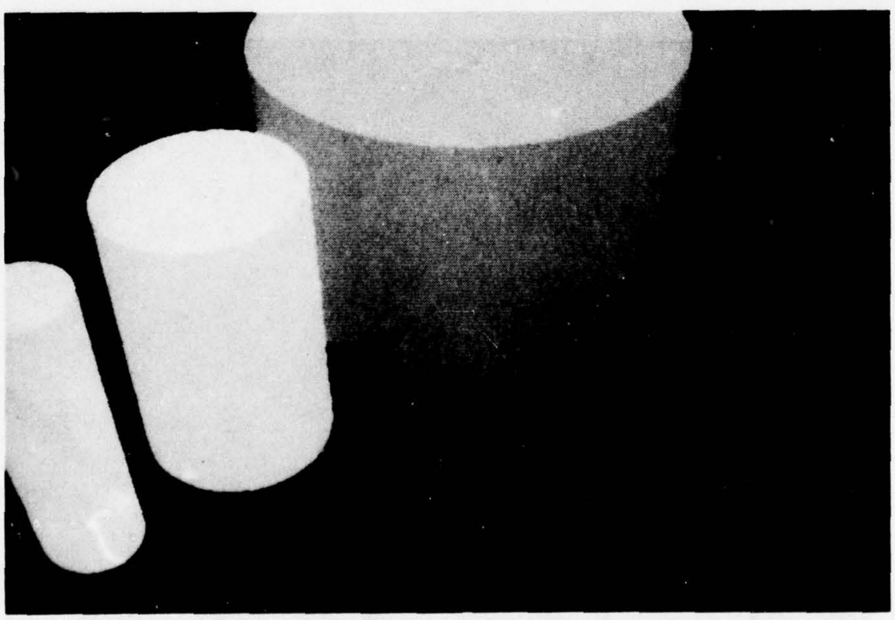

FIGURE 17. THREE CYLINDERS

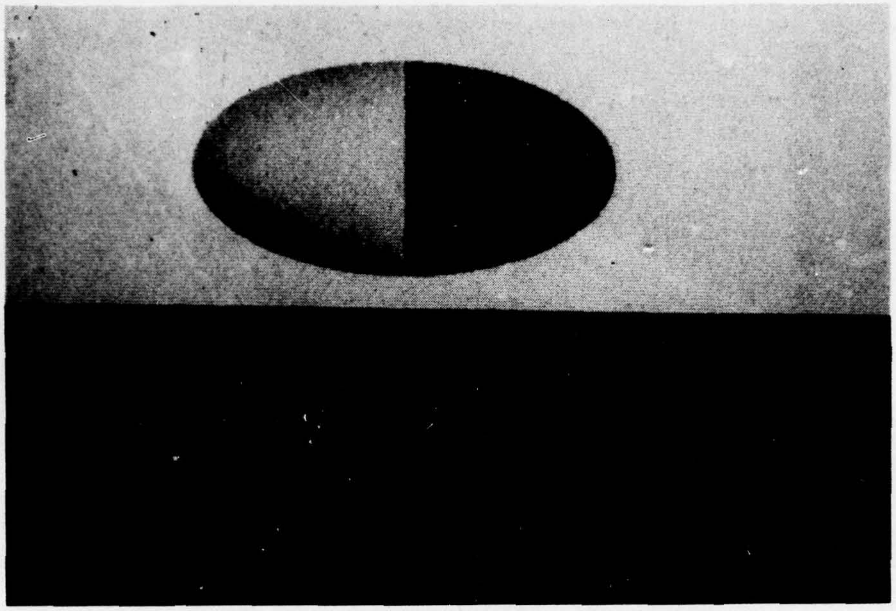

FIGURE 18. A PARTIALLY SMOOTHED ELLIPSOID

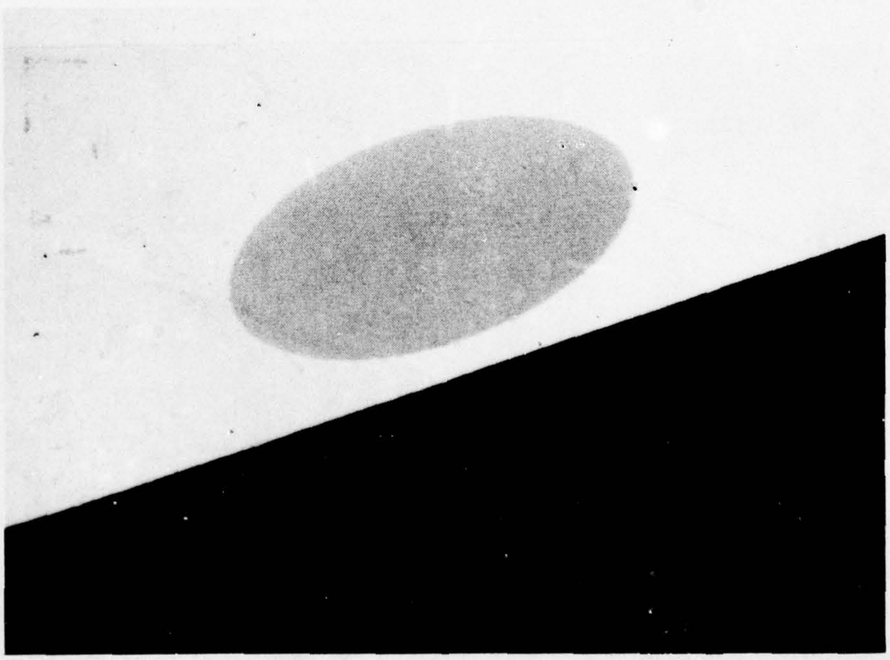

FIGURE 19. AN ELLIPSOID WITHOUT SMOOTH SHADING

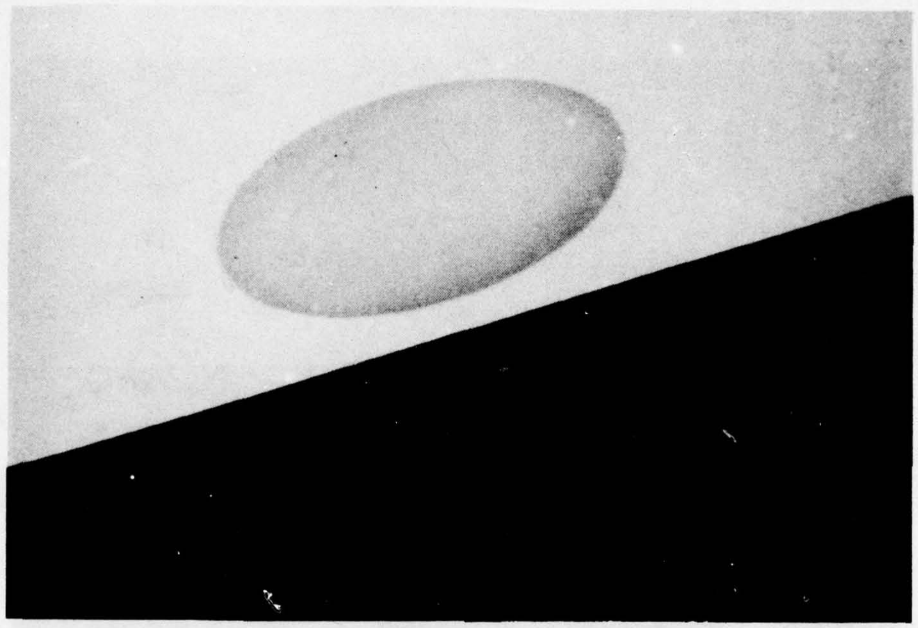

FIGURE 20. A SMOOTH SHADED ELLIPSOID

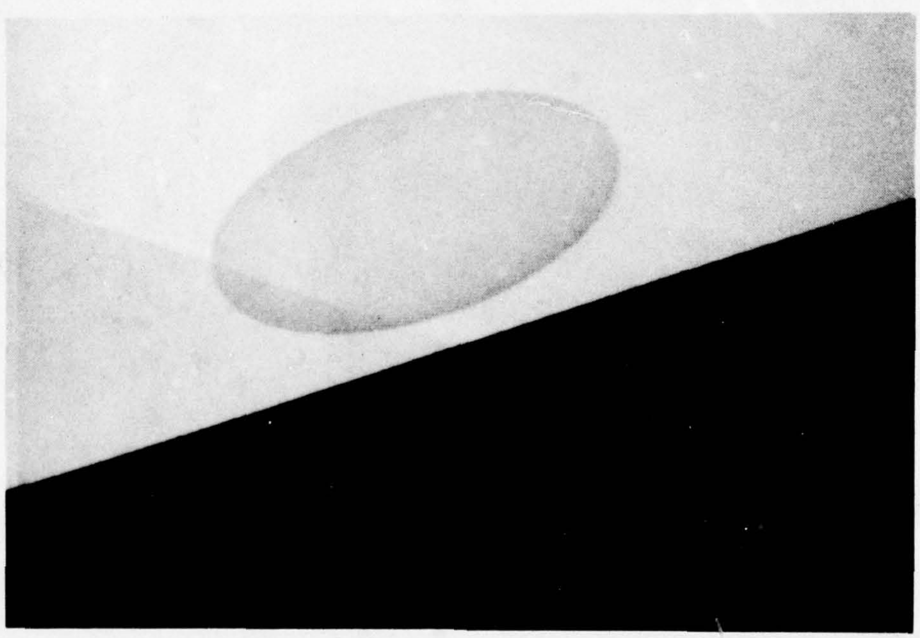

FIGURE 21. AN ELLIPSOID SMOOTH SHADED WITH EXACT CALCULATION OF NORMALS

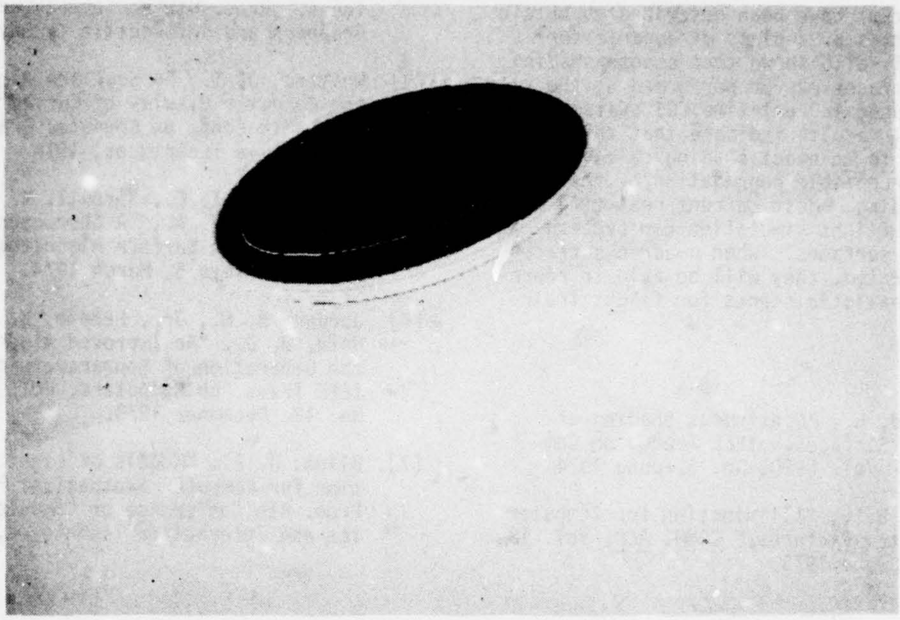

FIGURE 22. SHADE CONTOURS OF ELLIPSOID IN FIGURE 21

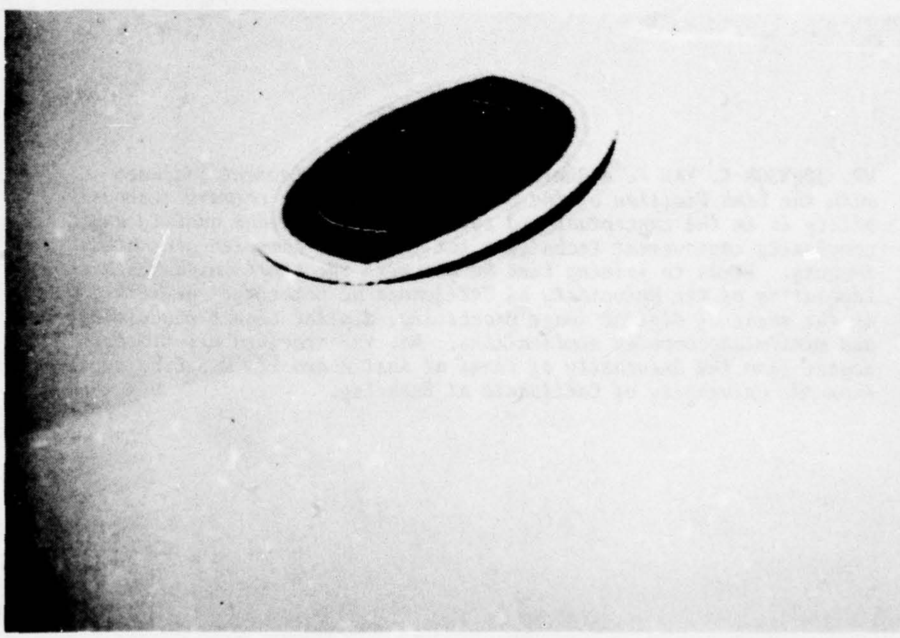

FIGURE 23. SHADE CONTOURS OF ELLIPSOID IN FIGURE 20

CONCLUSIONS

Algorithms have been described to obtain the silhouettes of a class of quadric surfaces. It is also shown that smooth shading of these surfaces can be performed at the frame rate used in real-time CGI systems. Experimental results indicate that the approximation to an exact shading calculation shows no perceptible degradation of the quality of shading. Most current real-time CGI systems for flight simulation can process only planar surfaces. When quadric surfaces are incorporated, they will be able to represent more realistic scenes for flight training.

REFERENCES

[1] Gouraud, H., "Continuous Shading of Curved Surfaces," IEEE Trans. on Computers, Vol. C-20, No. 6, June 1974.

[2] Phong, B.T., "Illimination for Computer Generated Pictures," COMM. ACM, Vol. 18, No. 6, June 1975.

[3] Blinn, J. F., "A Scanline Algorithm for displaying Parametrically Defined Surfaces," Proc. 5th Conference on Computer Graphics and Interactive Techniques, 1978.

[4] Whitted, J. T., "A Scanline Algorithm for Computer Display of Curved Surfaces," Proc. 5th Conf. on Computer Graphics and Interactive Techniques, 1978.

[5] Sutherland, I. E., Sproull, R. F., and Schumacker, R. A., "A Characterization of Ten Hidden Surface Algorithms," Computing Surveys 6, March 1974.

[6] Jordan, B. W., Jr., Lennon, W. J. and Holm, B. D., "An Improved Algorithm for the Generation of Nonparametric Curves," IEEE Trans. on Computers, Vol. C-22, No. 12, December 1973.

[7] Blinn, J. F., "Models of Light Reflection for Computer Synthesized Pictures," Proc. 4th Conference on Computer Graphics and Interactive Techniques, 1977.

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PAPERS PUBLISHED BUT NOT PRESENTED

EVALUATION OF FIREARM SIMULATION SYSTEMS FOR TACTICAL TRAINING OF POLICE

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INTRODUCTION

In recent years there has been a growing interest in development and use of weapons for simulations systems on the part of the military in this country and its NATO allies. This interest generally reflects the growing costs of training exercises where live ammunition is expended and the increased flexibility that simulation weapon firing permits in developing tactics and training personnel under actual fire.

It is noted that the police are generally confronted with the same requirements in their training programs and particularly in "SWAT" team exercises. Additionally, it should be recognized that the police perhaps have a greater need for field training with firearm simulation systems since, as a group, they are more frequently subjected to weapons fire and injury situations. The police officer then should also be afforded the opportunity to train with such systems where he could learn and practice the responses which would increase his chances of survival.

This paper describes the initial research effort to develop such a training system in cooperation with the Orlando Police Department.

STATEMENT OF PROBLEM

"While considerable progress has been made in recent years in the development of training programs for police officers, the total training effort in this country, when related to the complexity of the law enforcement task, is grossly inadequate." (1) Although this statement was made over 10 years ago and certainly progress has been made via the increasing availability of degree programs in community colleges and universities and special in-service programs, it still retains much of its validity today. In the last decade, the perplexing social and behavioral pressures within our society which prompted the initial emphasis on training have also spawned an ugly new dimension in the form of disrespect and antagonism toward police officers. Although this facet of the problem cannot be readily quantified, its existence and seriousness can be measured by the increase in assaults and number of police officers in today's society.

In most cases these situations involve a firearm of some type. The Criminal Justice Source Book, 1977 (2), for example, presents data which show that in-progress robberies and burglaries account for the highest incidence of officers killed on duty at about 26% over the years 1971-75. These incidents typically involve a firearm and exchange of fire.

Police training typically includes regular range firing of weapons at fixed targets and there are some ranges which present a series of pop-up targets along simulated city streets. These introduce a decision variable for the officer since some of the targets are friendlies. It is noted, however, that this training is far from the actual field situations where the targets fire back. There are numerous incidents, for example, where officers with excellent range records have been unable to hit a suspect who is firing at them. A more realistic training methodology is necessary.

The police are not the only ones faced with this training requirement. The Army, for example, is concerned with training troops and developing/evaluating tactics in small (squad) engagements. Additionally, their requirements escalate to all levels of weapons/personnel commitments.

The outgrowth of this interest has been the development of a series of weapon simulators which use coded laser beams to simulate the ballistic rounds. These range from tank cannon to the M-16 rifle. There are also other manufacturers who have developed weapon fire simulators for .38 cal. police issue revolvers. Typically, these systems involve a laser transmitter designed to mount on the real weapon which then can fire blanks and a laser round. Since these Laser Weapon Simulators (LWS) have been developed on DOD contracts, they may now be procured at a price which generally represents only the production costs in small lots. Presently, this is about $2500 per unit and, as more are produced, this cost should decrease.

The Army has also established several LWS training ranges around the country; however, they are far more sophisticated and costly than those required for police training. Generally, they are equipped with computer capabilities to record in real-time the position/status of all equipment, weapons and personnel. After a training exercise, these data can be used to evaluate the tactics and develop improved ones.

In discussing the training problem with responsible personnel involved in LWS training, it was learned that most of the effort to date has been on studying the larger engagement training exercises. It was understood that there is some current effort in the area of training small special forces to deal with terrorist attacks on nuclear facilities; however, these are classified.

Accordingly, the problem becomes one of developing a prototype training program using LWS so that the police can take advantage of this new technology.

TRAINING SCENARIOS

Information from actual field incidents were used to generate the Training Scenarios. Initially, incidents were selected with the assistance of experienced OPD personnel using case files and descriptive literature on the basis that they were representatives of weapon fire situations. These were then subjected to a three dimensional classification analysis, by type of incident such as robbery, burglary, domestic disturbance, etc., by participant involvement, such as suspects only, hostages, bystanders, and by location/prop requirements. The initial classification reflects the basic weapons fire situation with which the officer may be confronted. The second recognizes the degree of complexity which may escalate the basic incident, thus affording a series of training scenarios of increasing difficulty against which the officer can train and progress. The last classification reflects the logistics elements required to set up and conduct the training scenario. Although not as directly concerned with the training as such, the logistics can become a very important part of executing a successful training exercise and must be carefully considered in designing the scenarios.

It is also noted that in scenario generation care was taken to make the training cost effective by maximizing the number of trainees while simultaneously minimizing the support requirements. For example, at least two officer trainees were included per training exercise. This not only increases the training accomplished per exercise but also exercises the officers in teamwork and communications.

Each training scenario consisted of three basic parts, a Logistics Requirement Sheet, an Event Simulator Chart and a Performance Scoring Sheet. To better present this concept a prototype training scenario, Convenience Store Armed Robbery, has been presented by parts in Figures 1, 2, 3.

Figure 1 is the Logistics Requirement Sheet, which was designed as a system check-off and planning list for personnel, equipment and site requirements for the training exercise. It is expected that these items would become more detailed and standardized as further scenarios are developed and tested.

The Event Simulator Chart is the operational key to conducting the training exercise. As noted earlier each scenario was based on an analysis of documented incidents. A most important part of these analyses was the identification of events within the incidents which were common to a particular field situation.

FIGURE 1

CONVENIENCE STORE ARMED ROBBERY

LOGISTICS REQUIREMENTS SHEET

FACILITIES

- Convenience store with gas pump island
- Back door
- Places where suspects can hide but cover manager at door
- Available cover for officers
- Dumpster at side near back door
- Suspect vehicle

2 OFFICERS

- Standard field equipment and vehicle
- Weapons blank/ammunition
- Laser weapon simulator/detector harness
- Hand held radio/xmtr with local clear channel

2 SUSPECTS

- Consistent clothing from one episode to another
- Concealed weapon
- Laser weapon fire simulators/detector harnesses
- Money bag from hold-up

1 STORE MANAGER

- Appropriate clothing

1 DISPATCHER

- Hand held radio/xmtr with local clear channel

2 TRAINED OBSERVERS

- Score sheets for each suspect

2 VIDEO CAMERA OPERATORS

- 2 Video minicams and field support equipment

FIGURE 2
SCENARIO I

CONVENIENCE STORE ARMED ROBBERY

TIME LINE EVENTS

TIME (Min)	DISPATCHER	SUSPECT I	SUSPECT 2	STOCK MANAGER
0	(Contacts Car): "Two 13-P's at (Matter of fact-voice)	Armed with .38 revolver	In store Armed with rife and concealed .38 revolver.	In store
1	(If officers request more information call store)			
2	(Call officers): "Manager will meet you out front; everything is okay." (If officers request more information): "No more information is available."			
3.0				(Talking to police): "Everything's okay."
3.5		Hiding while manager is at door. Unless officers drive off, gets up from cover, grabs manager, fires a shot then pulls manager into store.	Hiding while manager is at door. Remains under cover until partner has fires the shot and returned inside. Discusses tactics with partner.	
4.5	Receive call from officers. Supply information as requested, e.g. estimated time of arrival of back-up.	Goes to door with manager in front of him and fires 3 rounds at officers. Takes manager back inside and hits him on the head.		(Goes to door with suspect behind him. pulled inside. Falls when hit on head. Remains on floor unconscious until exercise completed.
5.0		Goes to back door behind partner. 1) Partner will decide whether to exit unless he see officer. Exercise ends. 2) If not, exit behind partner. If at door and a shot is fired, officer yells he sees officer then goes back inside. Exercise ends. 3) If outside door & no sign of officers heads for cover or escapes. If officer then yells or fires, stops & follows instructions. Exercise ends when inside patrol car.	Goes to back door. Partner is behind him. Looks out back door. 1) If officer is visible, fire a shot or halts, do not exit through back. Exercise ends. 2) If no sign of officer, exit back door, head for cover or run to escape. If officer yells or fires a shot once outside, stops. Follows instructions of officers. If there is an opportunity to use the concealed weapon, use it. Exercise ends when inside patrol car without concealed weapon.	

FIGURE 3

CONVENIENCE STORE ARMED ROBBERY

SCORING PERFORMANCE SHEET

Observer ____________

Trainee ____________

Date ____________

RAW SCORE -	RAW SCORE +	OFFICER ACTIONS	NET SCORE
		RECEIVE CALL	
		1. Calls back	
		2. Acknowledges call	
		3. No response	
		4. Give location	
		OTHER ____________	
		WEIGHTING FACTOR (.05)	
		APPROACH	
		1. Stop car 50-75 ft. from store front entrance	
		2. Officers leave car at the same time	
		3. Separate - 1 officer to corner, 1 to front	
		4. Speak to manager	
		OTHER ____________	
		WEIGHTING FACTOR (.10)	
		SUSPECT FIRES SHOT	
		1. Find cover	
		2. Officer fires	
		OTHER ____________	
		WEIGHTING FACTOR (.15)	
		CALL HEADQUARTERS	
		1. Gives unit #	
		a. Taking fire	
		b. # Suspects	
		c. Possible hostage situation	
		OTHER ____________	
		WEIGHTING FACTOR (.10)	
		TACTICAL PLAN	
		1. Splits with partner	
		2. Communicate with one another	
		3. Covers side and back	
		4. One officer at front	

RAW SCORE -	RAW SCORE +	OFFICER ACTIONS	NET SCORE
		5. Officers are under cover	
		OTHER ____________	
		WEIGHTING FACTOR (.15)	
		SUSPECTS FIRES FROM FRONT	
		1. Officer fires	
		2. Officer does not return fire	
		3. Officer communicates with partner	
		a. "Suspects coming out front"	
		b. "Suspects going toward (out) back"	
		OTHER ____________	
		WEIGHTING FACTOR (.15)	
		SUSPECTS AT BACK DOOR	
		1. Officer at back informs partner	
		2. Allows suspects to clear door before he hails or fires	
		3. Suspects do not clear door before officer hails or fires	
		4. Partner in front maintains position	
		OTHER ____________	
		WEIGHTING FACTOR (.15)	
		SURRENDER	
		1. Officer challenges	
		2. "Lock fingers behind head"	
		3. "Kneel and sit on legs"	
		4. Calls partner	
		5. Approaches before partner arrives	
		6. Approaches when partner has arrived	
		7. Approaches with gun out	
		8. Each officer covers a suspect	
		9. Cuffs one hand and then the other	
		10. Searches before cuffing	
		11. Searches after cuffing	
		12. Finds concealed weapon	
		OTHER ____________	
		WEIGHTING FACTOR (.15)	
		TOTAL	

Observer Signature ____________________

In the convenience store robbery scenario example, a number of incidents of this generic type were examined to determine a basic sequence of events. These events were then used to create a generalized scenario which emphasized the subevents and key responsive actions required from each officer to ensure his effectiveness.

These events, in turn, were programmed on a time-line activity chart which described the activities of the participants, except those of the trainee officers, on a real-time base. This format required the trainees to respond against a series of controlled actions/events on the part of the other participants, and their actions are then evaluated to determine their proficiency against the given field situation. The times assigned to the events reflect a performance standard which, in turn, was derived from data on real situations and input from experienced officers. It is noted that, if the trainee actions are such that they do not respond within the allotted times, the suspects will complete their caper and escape.

The last part of the training scenario is the Performance Scoring Sheet which is illustrated in Figure 3. This document lists the best expected responses of the trainees to each sequential event in the exercise. These were determined from review of published Standard Operating Procedures, S.O.P., and augmented by consulation with experienced personnel at OPD. The purpose of the listing is to aid the instructor/observer in scoring each trainee as he performs the exercises. The format is designed to permit a quick notation representative of trainees' actions. Clearly, it is not possible to list all response actions and, accordingly, some space has been provided for penciled notations of unique observations. Each subevent section of the exercise has also been identified and assigned a weighting factor representative of its relative value to a successful solution of the exercise. This factor is used to modify the raw score by event section so that the subsequent total score will more correctly reflect the value of trainee actions.

The last considerations on scoring the trainee concerned his performance with the Laser Weapon Simulator. If during the weapons fire exchange the trainee sustains a hit, he clearly has failed the exercise. On the other hand, a hit on the suspects would signal a successful termination of the exercise. With multiple participants a hit on one of the trainees or suspects would not terminate the exercise but would shift the advantage to one side or the other.

SCORING METHODOLOGY

The scoring methodology was designed to provide the performance link between instructor and trainee. The format reflected considerations of the field environments, the fast-paced action of the scenario and the need to translate the trainee performance into a quantitative score.

The field environment and rapid scoring response required from the instructor-observer dictates a simple go/no-go type of evaluation. As noted in earlier discussion, key responses by the trainee had been previously identified for each subevent in the exercise. Initially, a rating scale method was considered to quantify these results; however, it was determined that this might overload the observer to the extent that his scoring responses would be harried. Additionally, the rating score might be challenged on the basis of its subjectivity. Accordingly, a check-off scoring method was selected. (4) This approach requires only that the observer match the trainee actions with listed responses. This simplifies the task and, further,it should reduce the incidence of questions on subjectivity of the rating since it involves only a match-up decision by the observer.

It was recognized that this approach would require additional effort to correctly design and standardize the expected responses; however, once developed, the scoring system would be much easier to use and administer. Standardization was accomplished by consulting with experienced officers and by modifying the expected responses as the training exercises were conducted to correct deficiencies.

As noted earlier each scenario was partitioned so that subscores could be obtained by major events. These events then sum to the total exercise and the trainee score would be determined on that basis. It was recognized, however, that these events will have different relative values in their contribution to solution of the exercise and, accordingly, weighting factors were needed to recognize this relationship. These factors were determined based on input from experienced officers as the expected response criteria were being generated. The individual inputs were structured on a method to quantify the relative importance relationship developed by West Churchman. (4) The Churchman method uses a stepwise procedure to test the relative value estimates obtained from a group of "experts." The weighting functions used in the scoring sheet,as presented in Figure 3,represent the averages obtained from the input of five experienced personnel at Orlando Police Department.

The final phase of determining the scoring methodology was concerned with development of performance standards for each scenario. Although expected responses to scenario events had been determined and weighted, some method of rating the relative performance of each trainee with his fellow officers was needed. In other words, what would constitute an acceptable performance score. This was determined by averaging the scores attained by experienced officers against each scenario. The standard deviation for each distribution was also calculated to determine if a score which was below the normal was significant; i.e., could be related to a cause,or perhaps was only a statistical deviation.

LASER WEAPON FIRE SIMULATIONS SYSTEMS

Three manufacturers were contacted for procurement of laser weapon fire simulation equipment. All had written off their hardware development costs against completed contracts so that their selling price now basically reflects only the small production lot costs.

Typically, each of the systems consists of three primary components. In all cases the detector and transmitter assemblies are operated by off-the-shelf replaceable batteries.

- A low-power laser transmitter equipped with a mounting bracket adaptable to the weapon.
- A trigger-action activating mechanism.
- A body harness containing a detector/alarm assembly to signal a hit.

Figure 4, 5 shows the systems for the M-16 rifle and .38 caliber police issue revolvers as presently developed. One manufacturer is currently under contract to develop additional .38 caliber revolver and shotgun systems to work with their basic M-16 detector system. It appears that by the end of 1979 all three basic police weapons should be available.

In operation,the simulators fire a coded laser pulse which activates a detector on the target body if within a given spot diameter. As shown in Figure 4, the body harness contains four detectors in front and back and an additional four on the head if desired. The detectors are placed to register a crucial hit on the participant within range of the given weapon.

FIGURE 4

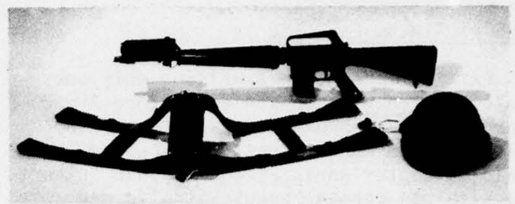
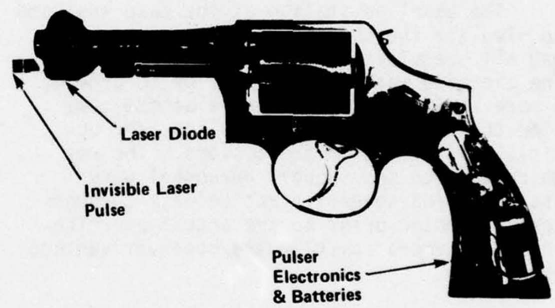


FIGURE 5



The range of the laser pulse is keyed to the range of the weapon being simulated. For example, the pulse for the M-16 rifle simulator is designed to produce a spot diameter at 400 meters which will trigger one of the body detectors. This design may introduce some detector problems if the simulator is fired at close range; however, it can be adjusted to produce a spot diameter compatible with the average range of the scenario encounter. Very close range firings will be limited to about 10 feet, which is the safe range for blank firings. This distance is well within the proven safe range specified for the laser transmitter power to prevent eye damage.

The present system also includes some sophisticated features which generally will not be required for police training. For example, the coded pulse permits the observer to determine who shot whom and where. Also, in the event a training exercise might be conducted without blanks, the trigger mechanism can be set to count the firings and disable the weapon until a reloading procedure has been accomplished.

All vendors have indicated their willingness to effect minor modifications in their basic systems to better fit the requirements for police training. The systems involved in this project, however, have been

limited to those available as demonstrators from the vendors.

PILOT TRAINING EXERCISE

At the time of this writing only one training scenario, Convenience Store Armed Robbery, had been exercised in the field. This exercise was conducted at the Navy Training Center Annex at the Orlando Jetport. The site was chosen because it afforded some isolation from the general public and the problem attendent with a curious crowd or a disoriented citizen who might take overt action thinking that he was witnessing an actual robbery.

The gasoline station at the base was used to simulate the convenience store since it had all prequisites required in the scenarios. The exercise was sceduled at 7 pm to provide a more realistic setting while at the same time there was sufficient daylight for observation/filming of the actions. The required police and support personnel were assembled and several practice walk throughs were conducted prior to the actual exercise to check camera coverage and observer vantage points.

A total of 4 officers participated in 5 training exercises based on variations of the training scenario. All were members of the Orlando Police Department. As scheduled,they reported to a staging area where all live ammunition was removed from their person and car, and they were issued six rounds of blank ammunition for their revolvers only. The two suspects were members of the Orlando Police Department Rescue Team (SWAT) and were armed with revolvers and a sawed-off shotgun. The officers were randomly paired and,after a short briefing to ensure that they were oriented, the dispatcher call was initiated to commence the exercise.

The vendors of the .38 caliber revolver and M-16 weapon fire simulators were invited to view the exercise so that they could become familiar with the weapon fire training scenario format and might then offer suggestions to more effectively incorporate their equipment. Cerberonics, Incorporated, demonstrated their .38 caliber revolver system, and made it available for use in the training exercise.

A number of tradeoffs/compromises pertaining to the application of all weapon fire simulation equipment were identified together with suggestions for additional development work. Generally, these involved compatibility of the sensor detection systems and range sensitivity for the three types of weapons used by the police. There also appeared to be a problem concerned with mix of vendor equipment. It would seem at this point that all weapon fire simulation equipment must be procured from the same source to ensure compatibility of transmitter/detection systems. It was noted that the audible hit alarm was difficult for the observers to hear during the actual exercise and a visual cue was also needed. Also, in close range encounters more detection area is needed on the body to ensure a hit registry. In the exercise the participants did not wear detector headgear. This would have helped and is recommended in future exercises.

Most of the errors noted during the exercises were concerned with communications. In one instance the situational status and request for backup was not relayed to headquarters correctly. Also,several times when the officers were separated and out of sight, they did not keep each other informed of the action in their area. This occurred when the suspects broke from the store at the rear door. In one instance the officer at the front did not know his buddy was pinned down and taking fire from both suspects. The pinned officer's lapel mike came loose and he was too busy fighting off the suspects to call. In one exercise the suspects escaped from the rear because the officers did not move quickly enough . Generally, however, the officers responded well. In one variation where a suspect posed as the store manager to ambush the officers, the officer had correctly taken cover and was able to hit the suspect when he moved to draw his weapon.

In staging the exercises, the major problem was associated with the suspects departing from the scenario script. This involved not only the action but also the action time line. Although these departures "livened-up" the exercises, they made it very difficult to score the officers correctly and consistently.

It appears the corrective action to be taken here would involve generation of more detailed scenarios and more detailed directions and control prior to the exercises. The officers posing as suspects are not professional actors and tend to react to the officers by improvisation. A more detailed explanation of the mechanics and objectives of the exercises to the officers would probably correct much of this problem.

COMMENTS AND OBSERVATIONS

The results to date appear to confirm the benefits predicted for the project. The training concept is effective and received good marks from the instructors and trainees who participated in the pilot exercises.

Additional work is needed, however, to develop scenarios which will better incorporate the laser weapon fire simulator equipment to realize its full potential in the training exercises. It must be recognized that the simulators do introduce some constraints such as being unable to fire through an opaque material such as paper.

Presently, a proposal for development of a regional training system for Central Florida has been submitted for consideration to the Training and Education Office of LEAA in Washington, D.C. As planned, this program would include purchase of 6 weapon fire simulator systems and development of 5 basic training scenarios each of which could be modified via minor changes in the scenario script. Once developed, the system would be maintained by the Orlando Police Department and used by all regional law enforcement agencies. Hopefully, this program would become a prototype which could be replicated throughout the country.

REFERENCES

(1) TASK FORCE REPORT: The Police, Presidents' Commission on Law Enforcement and Administration of Justice, U.S. Government Printing Office, Washington, D.C. 1967, pp. 36,37.

(2) SOURCE BOOK OF CRIMINAL JUSTICE STATISTICS, 1977, U.S. Department of LEAA, Table 3.122, pp. 460.

(3) PRINCIPLES OF PSYCHOLOGICAL MEASUREMENT, Helmstadter, G.A., Appleton, Century-Crofts, New York, 1964, pp. 186-187.

(4) INTRODUCTION TO OPERATIONS RESEARCH, Churchman, Ackoff, Arnoff, John Wiley & Sons, Inc., New York, 1957 pp. 138-141.

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A MICROCOMPUTER IMPLEMENTATION OF A SIMPLE VISUAL DISPLAY SYSTEM

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INTRODUCTION

Computer-driven visual display devices are receiving increasing user acceptance in the development and deployment of simulators and trainers for complex systems. Most of the attention paid these systems has been on the high end of the price/performance spectrum, with full-color, real-time displays for aircraft/spacecraft training simulators becoming the rule and not the exception. There exist other areas of potential application of computer-controlled visual systems, specifically in low-cost trainers designed for initial familiarization or proficiency maintenance on specific areas of systems performance. Such trainers do not need the fidelity or flexibility required of complex systems, but can be optimized for a specific function, such as training pilots for contact approaches to airfields.

This paper discusses some of the basic aspects of implementing "simple" computer graphics and presents an example in the form of simulated night landing displays at Herndon Airport in Orlando, Florida. The three-dimensional projections were calculated and displayed on a video monitor in the form of two-dimensional scenes. Motorola 6800 Microprocessor-based hardware was used as the interface to a video monitor. A description of the various operating parameters for simulated flight landings is presented. Included in the discussion are various pictorial representations of simulated landing approaches at Herndon Airport, and suggestions for improving the performance of the system are outlined.

GRAPHIC PRINCIPLES OF FLIGHT SIMULATION

Since a display screen is a two-dimensional space, one can not display three-dimensional flight perspectives without the use of some mathematical transformations. Three-dimensional coordinate transformation equations must be generated in order to convert flight perspectives, which are three-dimensional, into two-dimensional points.

The three coordinate transformations that must be considered are:

1. Rotation
2. Translation
3. Clipping

For each of these transformations, equations and associated matricies must be established so that the proper perspectives can be generated.

A general rotation in the three-dimensional XYZ-space assumes that the world rotates around the viewer. This in essence is the viewers direction and assumes that the viewers location is at (0, 0, 0) in three coordinate space. A general rotation may be accomplished simply by multiplying a 3 x 3 matrix by a three element vector (1). This matrix only has to be generated once per each viewing direction since it applies to all points for that view.

The rotation or viewer's direction consists of four parameters:

1. Pitch (P)
2. Bank (B)
3. Heading (H)
4. Angle of View (V)

Pitch is a floating point variable that specifies the angle of inclination from which the viewer looks at the scene. Bank is a floating point variable representing the angle at which a viewer's head is tilted sideways when viewing the scene. Heading is the direction the viewer is facing while standing on the XZ plane.

The 3 x 3 matrix, which when multiplied by a three element vector, used to rotate the scene about the origin is shown in Figure 1. This figure shows the rotational matrix being multiplied by the original 3D space coordinate point yielding the rotated point.

The fourth parameter used in the rotation of the original base case is called the viewer's field of view. This parameter is similar to

the lens on a camera. This parameter limits the angle that the viewer will see when making the approach to the landing strip.

Field of view is a floating point value representing the tangent of the half field of view. A value of one represents a forty-five degree half field or ninety-degree full view of field. A value of three would represent a narrow telephoto view.

Anytime a change of viewer's direction or rotation takes place, a subroutine must take the change in pitch, bank, and/or heading, as well as field of view and create a new predetermined transformation matrix. This new transformation matrix must then be multiplied by the original data to create a new rotated scene.

TRANSLATION

The viewer's location in flight simulation is always considered to be at (0, 0, 0) in a coordinate space. When the position of the aircraft is at a location other than (0, 0, 0), the points in the data base must be translated while the viewer remains fixed. In other words, the world moves and the viewer remains fixed.

Translation of a point is performed by adding a positive or negative constant to each point of the three-dimensional data base.

CLIPPING

The simple application of translation and rotation to produce a perspective image has two undesirable effects.

1. Objects behind the viewpoint may appear on the screen.

2. Objects may exceed the prescribed limits of the viewpoint.

These effects are eliminated through the use of a clipping algorithm. The operation of line clipping and coding in the program is an extensive process and thus slows down the output from the microprocessor to the video display terminal. That part of the program which performs the algorithm of coding and line clipping is written in BASIC language and thus adds additional computational time to the process. Even though the process is rather slow, it does not affect the accuracy of the transformed view of the field on the video output monitor.

PROJECTION

Once the clipping process yields a line that is visible on the screen, then a perspective projection must be performed. Generating a true perspective image requires dividing by the depth of each point (2). Dividing each starting and ending point of a line that falls within the viewing pyramid by the depth and then multiplying by the half width of the particular video output monitor screen that is being used will give the true perspective image.

A key factor in the projection of a point on the screen is the order in which the transformations are calculated. The position of a point on the display screen which corresponds to a point on some object will be different if different orders of translation and rotation are calculated. For example, if the viewer's location in space (translation) is considered before his viewing direction (rotation), a different projection would result if location had been considered after direction.

Throughout the program for flight display, the following is the order in which the transformations are calculated:

1. X, Y, Z, translation.

2. Heading (rotation about Y axis).

3. Pitch (angle of view to the X, Z plane).

4. Bank

SOFTWARE

Once the input array and control parameters have been integrated into the body of the program, the subroutines shown in Figure 2 are called. These subroutines are called upon to transform each starting and ending point of the data base and to send the resulting screen start and end points to the display device to be displayed.

A commercially available graphics package (1) was used to provide much of the processing logic in the program sections performing the mathematical transformations.

The matrix generator subroutine generates the 3 x 3 transformation matrix requried for rotation. The input parameters P, B, H, and V are used to generate the rotational transformation that will be used in the 3D to 2D converter. Contained within the matrix generator subroutine is the sine/ cosine subroutine. This subroutine generates the cosine and sine of a value in degrees. This subroutine is needed because BASIC language does not have trigonometric functions. This matrix need only be calculated once for the given control parameters. All lines in the scene will use the same transformation matrix.

The program must then feed the array of 3D input points to the matrix multiplier subroutine. The matrix multiplier subroutine takes the viewer's location values and adds them to the start and end points of each line in the data base one line at a time. The points are then multiplied one at a time by the transformation matrix calculated in the matrix generator subroutine. Each rotated start and end point is then transferred to the clipping subroutine.

The clipping subroutine determines if the line just translated and rotated is on the screen or off the screen and accordingly displays, clips, and displays, or eliminates it. As each starting and ending point for a line is translated, rotated, and has the necessary clipping performed, it must be sent to the display device driver subroutine. The display device driver subroutine was written in M6800 machine language and contained several subroutine options within the program; these were the Erase and Draw routines.

The Erase subroutine is run once each time a new transformation matrix has been calculated. The subroutine clears the video monitor display of any previous objects. The Draw subroutine accepts the data from the 3D to 2D converter and outputs to the video display monitor electrical impulses that correspond to scan lines on the display image. Each time the 3D to 2D converter calculates a new translated, rotated, and clipped line, the Draw subroutine is called to output to the video monitor.

Once all the lines from the base data have been sent to ask for a new position and direction, the program will check to see if the input variables have changed. If none of the variables have changed, the program will not erase the screen, but instead ask again for new viewer parameters. Once any one of the six parameters are changed, the program will then calculate a new transformation matrix, erase the screen, and calculate a new display image on the video monitor.

This program was written with the versatility to include many different data bases, larger or smaller screens, wider or narrower fields of view, and different positions and directions. The major portion of the program is written in the BASIC language, which makes the calculations of perspectives slow.

HARDWARE

The computer hardware used in this study was built from kits produced by the Southwest Technical Products Corporation of San Antonio, Texas. The major components of the system and the associated costs were as follows:

1. M6800 microcomputer (32K RAM, 1K ROM) at an approximate cost of $1000.
2. Dual mini-floppy disk drive at an approximate cost of $1000.
3. Graphic Interface Terminal at an approximate cost of $200.
4. Video output monitor at an approximate cost of $200.
5. Console Terminal at an approximate cost of $500.

The dual floppy drive has the ability to store programs on small magnetic disks. The magnetic disk affords the ability to store many different data bases which are readily available to be called up by the operator. This gives the operator the ability to change the training enviroment from one area to another within seconds.

The graphic interface terminal serves as a buffer between the video monitor and the M6800 microcomputer. The graphic interface takes digital output data from the microcomputer and converts it to a composite video signal for display.

SYSTEM OPERATION

The most crucial part of constructing a three-dimensional graphic program is testing the system to see if results are what is expected. The entire process of rotation, translation, clipping, perspectives, and visual display must be integrated into a software module or modules that have coordinate values of a point in the three-dimensional space.

This module can be depicted as a transfer system as shown in Figure 3 (3). The input consists of points X, Y, Z, in the three-dimensional space. Along with the inputs are eight transformation parameters.

The three angles of rotation P, B, and H.

The three translation parameters X, Y, and Z.

The two scaling factors W and V.

The output variables that one is expecting to display are X_p and Y_p, which are in 2D screen coordinates.

The intended purpose of any flight simulator is to accurately generate the perspective views of the data base for a given position. The data base selected for this study was that of Herndon Airport located in Orlando, Florida. As viewed in Figure 4, Herndon has two

major runways in a basic X configuration.

In order to simulate flight landings on the runways at Herndon Airport, the three angles of rotation and the three translation parameters must be supplied to the program. Figure 5 depicts various points on and off the runway that were to simulate flight landings. Table 1 is a listing of the various points on the runway layout that have been inputted to the computer and the translated and rotated picture displayed on the video monitor.

In order to simulate an approach landing on the runways at Herndon, a general view of the field was generated to provide an overall validation of the model performance. Figure 6 is a view of Herndon Airport when the values of the angles of rotation and translation parameters are:

X(3) = 0 (origin of X-axis)

Y(3) = 5000 feet (altitude)

Z(3) = 0 (origin at Z-axis)

P = -90^{O}

B = 0^{-}

H = 0^{O}

Approach landing to Runway 7 will be depicted in a series of figures. Figure 7 is a view of Herndon Airport when the values of the angles of rotation and translation parameters are:

X(3) = -10,000 feet

Y(3) = 3,000 feet (altitude)

Z(3) = 10,000 feet

P = -15 degrees

B = 0 degrees

H = 50 degrees

Figure 8 is a view of the airport from:

X(3) = -5,000 feet

Y(3) = 1,500 feet

Z(3) = -5,000 feet

P = -20 degrees

B = 0 degrees

H = 50 degrees

Figure 9 depicts an even closer view of Herndon's Runway 7. The parameters are:

X(3) = -2,500 feet

Y(3) = 800 feet

Z(3) = -3,500 feet

P = -25 degrees

B = 0 degrees

H = 50 degrees

Examination of Figure 10 shows that the plane is about to touch down on Runway 7. The parameters are:

X(3) = -1,700 feet

Y(3) = 200 feet

Z(3) = 2,700 feet

P = -25 degrees

B = 0 degrees

H = 50 degrees

The final approach and touchdown scenario on Runway 7 is depicted in Figure 11. The parameters are:

X(3) = -1,500 feet

Y(3) = 100 feet

Z(3) = -2,400 feet

P = -15 degrees

B = 0 degrees

H = 50 degrees

CONCLUSIONS AND DIRECTIONS FOR FUTURE STUDY

The evolution of computer graphics with its associated graphical displays has without a doubt surfaced as one of the most fascinating areas of computer technology. The essence of this research was to explore the feasibility of a microprocessor to demonstrate the use of low-cost computer graphics for flight simulation visual display. Many large-scale flight simulators are available that utilize computers to create flying conditions. A major obstacle to widespread use of these relatively high costs is associated with the complexity of a total systems simulation. There is a large potential demand for limited-function flight simulators and other specialized trainers if certain parameters can be achieved:

1. Low Cost: The system must be designed to

be implemented on a small computer, equipped with a relatively small highspeed memory, a mass storage device, a linedrawing display and input devices appropriate for the intended application, possibly including a keyboard and joystick.

2. Versatility: The use of a local dedicated computer rather than a remote time-shared system enables the system to provide a good response.

3. User- Oriented: The system is designed to be operated and programmed by interaction with a single, high-level language.

Because display devices have limitations, display systems are a compromise between the interests of men and capabilities of the equipment (4). Two of the major limitations of the hardware used in this study were resolution and round-off.

Resolution is a measure of discrimination within a fine detail. Resolution depends partly upon the visual activity of the eye and partly upon the resolution of the display itself. The resolution of a display depends upon the size of its screen, the strength of the phosphor and the graininess of the web upon which the display is projected. Thus, some of the blurriness which shows up on the pictures has to do with the size of the screen which causes resolution.

The second limitation on the screen image is associated with numerical round-off. The graphics display hardware can only accept integer values as inputs to the video display unit. Thus, some of the lines exhibit a smooth appearance, such as the center lines of runways because of the round-off that is inherent in a grid definition of only 64 x 96 points. This is an inherent limitation of the equipment that is currently being used.

One major area for future research is to increase the speed at which the new projections are calculated and projected on the video monitor. In order for the system to be used for actual flight simulation, the program must be able to generate 20-30 new projections and associated display updates within one second. This performance can conceivably be approached with microprocessor based-systems by converting the program from BASIC to machine language and/or by investigating the possibility of distributed computers using multiple microprocessors.

The second area where additional research can be done from this study is to make the position and direction parameter inputs come from cockpit controls and displays instead from the console terminal. These inputs can be generated by the use of transducers and can be fed directly into an analog to dig tal converter. The outputs from the converter would then be the inputs to the microprocessor to be used for generating new projections.

It is clear that great advances have been made in building highly versatile, and user-oriented, graphics transformation processors. It is anticipated that the next few years will bring about the development of high-quality, high-performance, and inexpensive training adjuncts to large scale display simulators that are currently in use.

REFERENCES

1. Sub Logic, Inc., 1976. "BASIC microcomputer graphics user's manual." Tampa, Florida: Sub Logic. Inc.

2. Newman, W. M., and Sproull, R. F., 1973. Principles of interactive computer graphics. New York: McGraw-Hill.

3. Giloi, W. K., 1978. Interactive computer graphics. Englewood Cliffs, New Jersey: Prentice-Hall.

4. Miller, W. E., 1968. "Visual information display systems." Survey presented to National Aeronautics and Space Administration, Washington. D. C.

	(Feet)			(Degrees)		
No.	X	Y	Z	P	B	H
1	-6000	600	-6500	-45	0	40
2	-3500	400	-3700	-45	0	40
3	-2000	200	-2800	-35	0	40
4	-1500	100	-2400	-30	0	40
5	-1000	100	-1900	-30	0	225
6	1400	200	-3000	-15	0	140
7	1600	200	-3600	-35	0	145
8	2500	500	-3900	-35	0	145
9	-5000	800	2600	-40	0	-45
10	-3500	300	1500	-40	0	-45
11	-2600	200	900	-35	0	-45
12	-2300	200	700	-10	0	-45
13	-1000	300	-500	-35	0	135
14	4200	800	3000	-35	0	225
15	3500	600	2300	-35	0	225
16	3000	400	2000	-40	0	225
17	2700	200	1800	-30	0	225

TABLE 1

Three-Dimensional Data Points for Various Landing Approaches to Herndon Airport

$$X'Y'Z' = \begin{bmatrix} XYZ \end{bmatrix} \begin{bmatrix} \begin{bmatrix} \text{COS H} \quad \text{COS B} \\ + \\ \text{SIN H} \quad \text{SIN P} \\ \text{SIN B} \end{bmatrix} & \begin{bmatrix} -\text{COS H} \quad \text{SIN B} \\ + \\ \text{SIN H} \quad \text{SIN P} \\ \text{COS B} \end{bmatrix} & \begin{bmatrix} \text{SIN H} \quad \text{COS P} \end{bmatrix} \\ \begin{bmatrix} \text{COS P} \quad \text{SIN B} \end{bmatrix} & \begin{bmatrix} \text{COS P} \quad \text{COS B} \end{bmatrix} & \begin{bmatrix} -\text{SIN P} \end{bmatrix} \\ \begin{bmatrix} -\text{SIN H} \quad \text{COS B} \\ + \\ \text{COS H} \quad \text{SIN P} \\ \text{SIN B} \end{bmatrix} & \begin{bmatrix} \text{SIN H} \quad \text{SIN B} \\ + \\ \text{COS H} \quad \text{SIN P} \\ \text{COS B} \end{bmatrix} & \begin{bmatrix} \text{COS H} \quad \text{COS P} \end{bmatrix} \end{bmatrix}$$

Where $\begin{bmatrix} X'Y'Z' \end{bmatrix}$ = Rotated Point

$\begin{bmatrix} X \ Y \ Z \end{bmatrix}$ = Original Point

P = Pitch

B = Bank

H = Heading

Figure 1. Rotational Matrix multiplied by original 3D space coordinate point yielding the rotated point

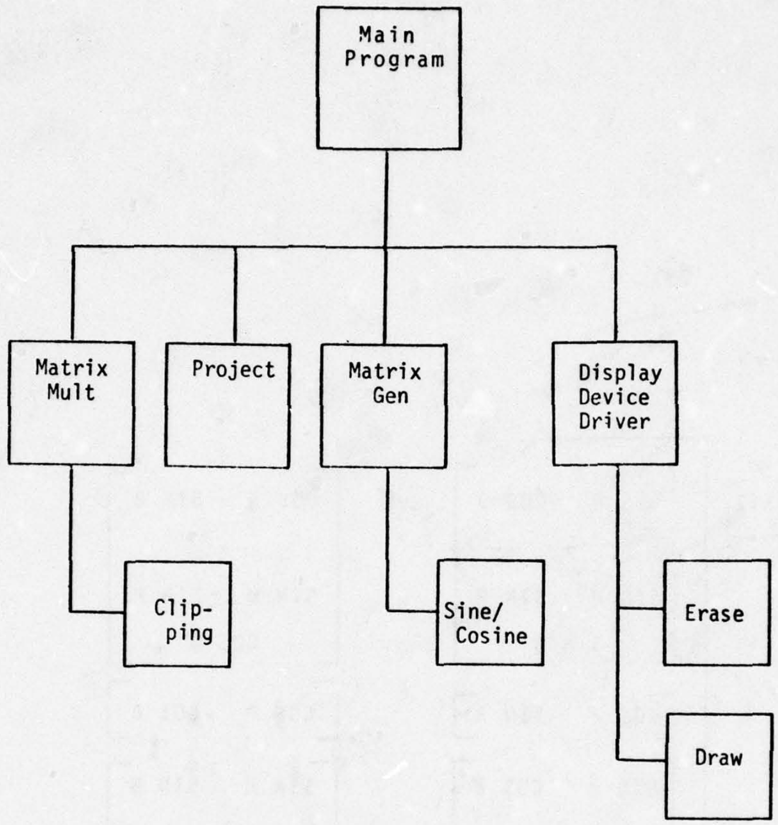

Figure 2. Subroutine Structure for Flight Simulator

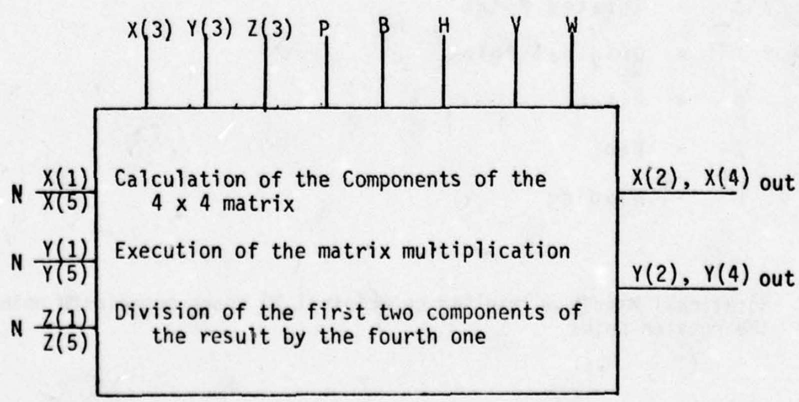

Figure 3. Transfer System view of a module for rotation, translation, clipping, and perspective on a line from (X_1, Y_1, Z_1) to (X_5, Y_5, Z_5)

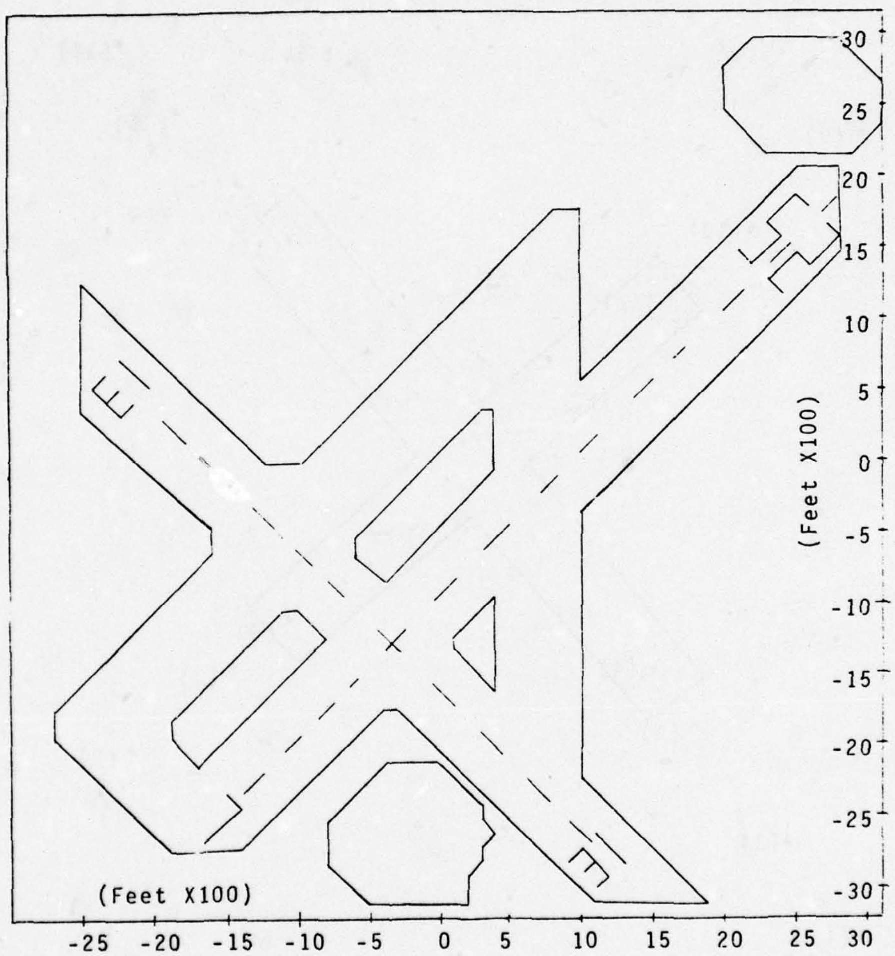

Figure 4. General Layout of Herndon Airport and Associated Runways

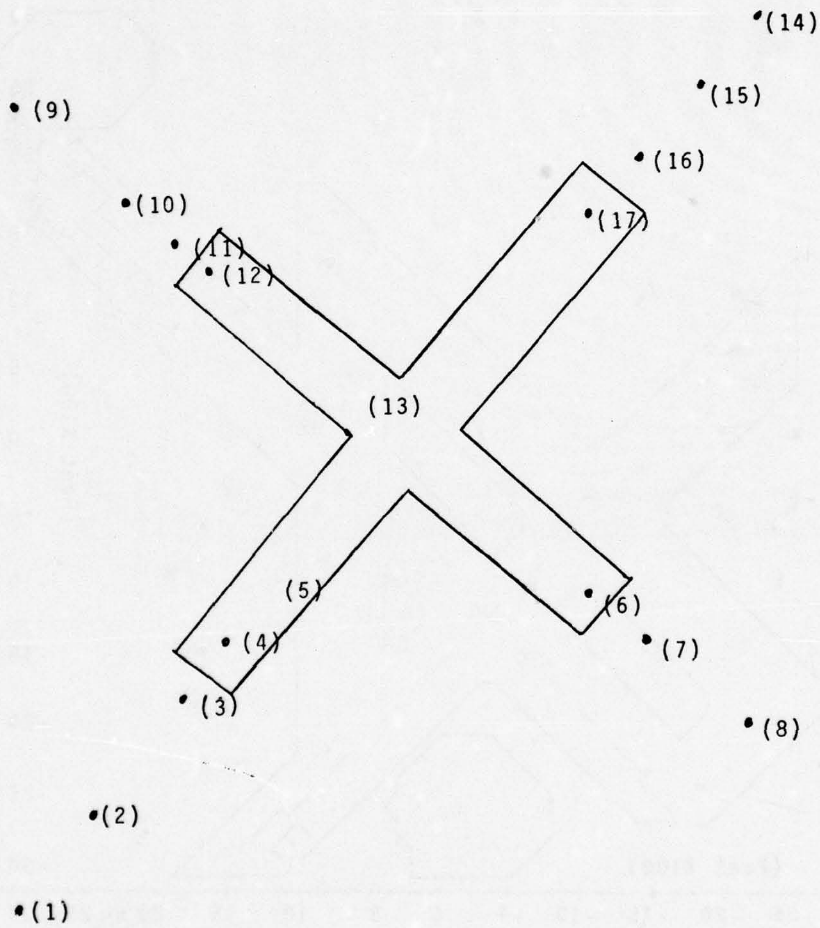

Figure 5. Point Approaches to Herndon Airport

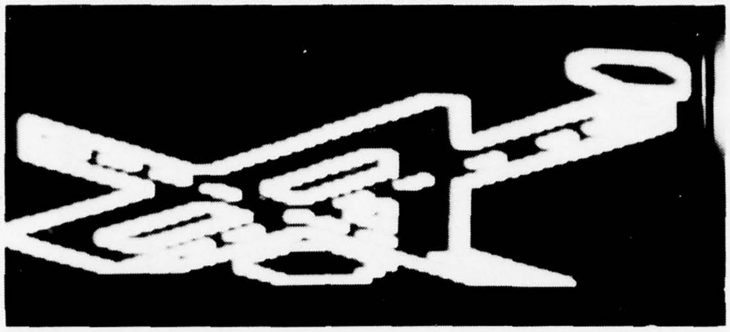

Figure 6. Aerial View of Herndon Airport at 5000 Feet

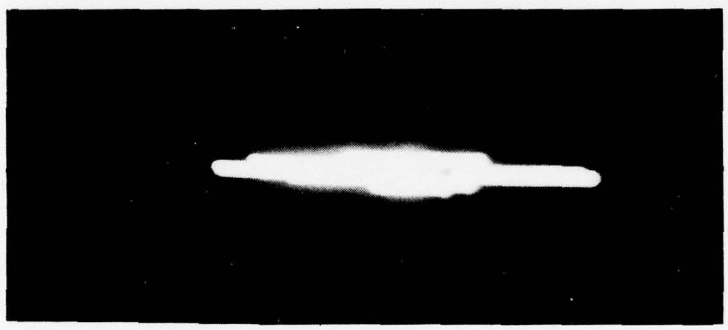

Figure 7. Aerial Approach to Runway 7 at 3000 Feet Altitude

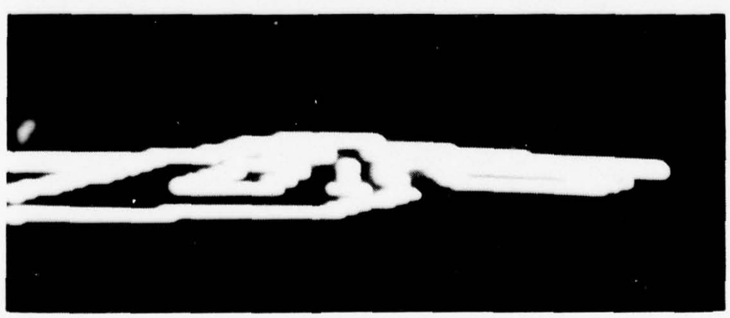

Figure 8. Aerial Approach to Runway 7 at 1500 Feet Altitude

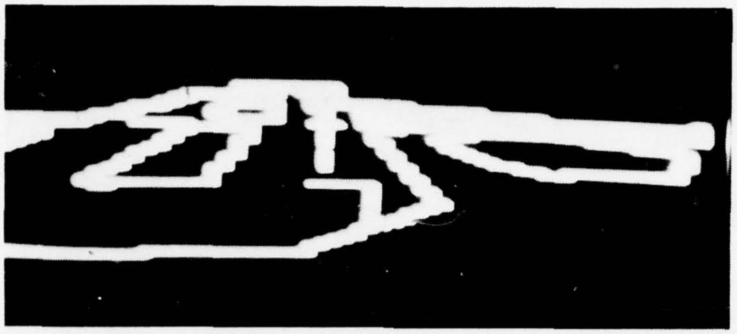

Figure 9. Aerial Approach to Runway 7 at 800 Feet Altitude

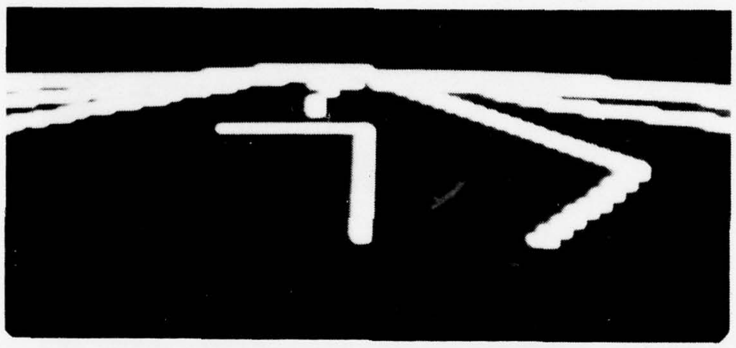

Figure 10. Aerial Approach to Runway 7 at 200 Feet Altitude

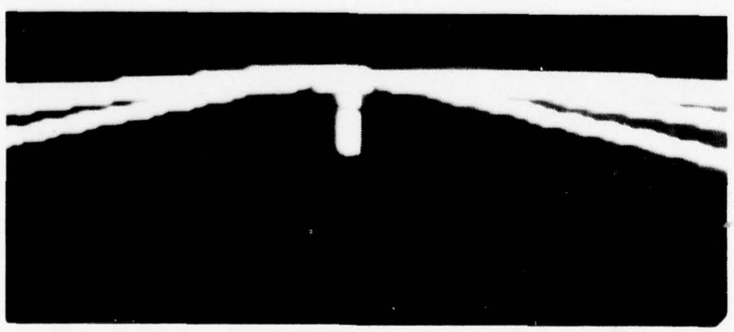

Figure 11. Aerial Approach to Runway 7 at 100 Feet Altitude

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SOFTWARE LIFE-CYCLE COST

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ABSTRACT

Life-cycle cost estimation can be a means to avoid mistakes in system design that would result in large costs. Successful life-cycle forecasting, however, requires the ability to predict, with reasonable confidence, the total cost (life-cycle cost) associated with the development, acquisition, and ownership of a system. Unfortunately, life-cycle cost analysis has not been satisfactorily applied to computer software systems. Unlike hardware, logistic parameters for software are difficult to predict and measure. Thus, software costs have been difficult to predict. Life-cycle costing of hardware systems has evolved into a systematic approach involving concept formulation, contract considerations, development/production and operations/disposal. Such an approach has been useful to define areas of high-support costs, evaluate alternative support policies, determine impact of operational requirements on support alternatives, and to provide for long-range cost prediction. This paper examines the cost of real-time simulation computers with emphasis on computer software life-cycle costs.

INTRODUCTION

Computers are no longer the mystic entity they once were, but they do present problems to any management which does not understand the complexity of supporting computers that are an integral part of a complex training system. Cost overruns, schedule slippages, and inadequate performance have been commonly encountered in the procurement of such systems. Even after acceptance of these systems, modifications are commonly required to correct faults in the systems.

An improved approach is necessary. It is not enough that hardware and software be developed as a total system, with the usual consideration given to hardware/software tradeoffs. Even an enlightened user with a total-system approach to design and acquisition is likely to experience problems in the support of software for computer-controlled systems, unless software is given special consideration. Future software modifications must be anticipated and planning provided for them.

Software is, of necessity, an item requiring maintenance and must be modified to correct errors, to improve system response, or to reflect changes in operational equipment. There appears to be a shortage of personnel who are capable of making sound decisions regarding the planning for software support of this type.

The development of a maintenance concept is considered one of the most important steps in planning for system support during its life cycle. Unfortunately, maintenance and enhancement of software is viewed as being of lesser importance than the design and development of software, and planning for software support is often inadequate.

Activities which keep systems that meet user needs (maintenance and enhancement) are a necessary expense. It was determined by Swanson (12) that only seventeen percent of such activity was for corrective maintenance. That is, it was necessary in response to the assessment of failures. Adaptive maintenance (performed in anticipation of changes within the data processing environment) or perfective maintenance (elimination of inefficiencies, performance enhancement, and improvement of maintainability) was required in the remaining eighty-three percent of the cases, however.

When one considers that forty to seventy-five percent of total systems engineering and programming resources (2,10) are involved in software maintenance and that this cost is often obscured in other operating expenses (7), the need for effective planning for software maintenance becomes financially clear. Although total expected cost was being used as early as 1968 (3) to evaluate proposals for purchase of computer software systems, software maintenance was not a consideration.

Adequate planning must include all factors that will influence the cost over the full-system life cycle. Anticipated software maintenance is an important part of the life-cycle cost, yet there is a dearth of historical data. Predicting the maintenance costs of computer software is a difficult task, not unlike estimating software development costs.

Support problems limit the operational readiness and availability of any system. Typical is maintenance down time. Much effort has been expended to increase the mean time between failures and to decrease repair time of hardware. Personnel are trained to reduce the adverse effect of failure and malfunction. Logistic support may be used as a constraint in hardware design. Alternative designs are considered if existing designs create support problems. Software has not received this

attention.

Software maintenance costs may possibly be reduced by extensive effort during the development phase. Modifications are relatively cheap during the early software development while those required after the system becomes operational may be twenty times as expensive. The nature of training systems is such that software modifications must be introduced as operational equipment is modified, or even to simulate other similar aircraft. It is possible that in the early planning stages, one could consider the need for future modifications and plan means to easily incorporate these at a later date.

In 1977, Department of Defense (DOD) software costs exceeded $3 billion. Sixty-eight percent of this was for development; only thirty-two percent was allocated to operation and maintenance (1). There has been little planning for software maintenance. Historically, software has included a large number of errors. Although errors are introduced in the system design phases, corrections must often be instituted at the most critical points (during test, evaluation, and acceptance). Consideration must be given to software development using the same concepts and approaches that have successfully controlled hardware costs.

The cost of software is skyrocketing, and results still fail to meet expectations. Applications of engineering techniques could improve this area. Computer technology has reached an era where hardware development costs are declining per unit of capability. This trend is likely to continue. Software development costs (as measured in lines of code per manhour) are rising. The difference is that hardware design is based upon engineering principles and manufactured in highly automated processes. These principles do not exist for software. In addition, managers do not understand software and are unable to generate adequate specifications for its performance, design, or development (9).

Life-cycle costing has required the ability to forecast the amount of the cost with reasonable confidence. This concept must be expanded to include all those factors, including software, which significantly influence the cost of support over the life cycle of the system.

SOFTWARE

Software became an item of significant cost in training devices with the increased use of digital computers for the simulation of weapon systems. In the training environment, extremely complex algorithms must be programmed to simulate the weapon and its environmental characteristics. Such software is costly, and neglect of this software in planning a training device can result in unsatisfactory operation and increased life-cycle cost. With the introduction of new hardware and shrinking budgets, control of software cost is of increasing concern.

Although little data are available on the cost of dedicated computer systems, an examination of automatic data processing (ADP) costs reveals much about software costs in general. It was found (5,9) that forty to forty-five percent of the $6.2 to $8.3 billion cost of 3,460 DOD computer systems in 1973 went for software. The cost of software required in the Naval Training Equipment Center's training devices is sixty-five to seventy-five percent of the total systems cost (6).

SOFTWARE PRODUCTION

Software for military computer systems can cost several million dollars and require several years to develop; yet may result in ineffective hardware incapable of meeting program milestones. The production of this software (systems analysis, design, and programming) consumes approximately twenty-three percent of the ADP costs of DOD computer systems (9).

One of the important requirements for management planning is an accurate estimate of the resources required to complete a project. Estimating the cost of software production is difficult. Considerable design work, good software specifications, and intensive project planning are required for realistic estimates. One common problem has been the poorly estimated cost of computer program development.

Estimates of program development costs are usually based on the number of lines of code to be written. Yet one of the most difficult questions to answer is "how long will it take to program this application?" Programmer productivity varies from 1,000 to 4,000 program statements per year. The average is 2,500 including time to block diagram, code, and test (11). Although there are many significant variables in predicting programming effort, the one most commonly used is delivered lines of code.

Basically, three factors (4) affect the cost of computing: (1) The job to be done (the number of program instructions). This has usually been poorly estimated. Safety factors commonly range from twenty to four hundred percent. (2) The resources with which to do the job; and (3) The environment in which the job is done. Although accurate estimation of computer programming costs is an important prerequisite for effective

programming management, such estimates have been historically unreliable.

SOFTWARE MAINTENANCE

The cost of software maintenance is staggering! Seventy percent of the overall cost of software in the Air Force goes into software maintenance (5). Many ADP installations apply seventy percent of the time of systems analysts and programmers to software maintenance functions (8). Currently, forty percent of overall hardware/software effort is going into software maintenance and this is expected to grow to sixty percent by 1985 (2). It is maintenance of software that consumes a major part of system life-cycle cost. This cost increases as the life cycle is extended.

One item of importance, especially in long-life training system computers, is software maintenance. It has been estimated that program development costs seventy-five dollars per instruction, while maintenance could cost as much as $4,000 per instruction (11). The higher cost has been attributed to poorly designed, poorly structured, and poorly documented older software.

Future software maintenance requirements are difficult to estimate. Extensive data on predicted reliability and maintainability has been required for life-cycle cost analysis of hardware. Little historical data of this type is available for software.

Even in highly reliable systems, malfunctions can be expected and provisions for their correction must be made. Planning for long life-cycle support requires provisions for personnel, money, and other support factors. Some reliable estimate must be made of the effort required and software mainenance must be included.

Kirby (6) found that during the average useful life of eleven years for a major training device, seventy percent of the software costs would be spent on maintenance. In addition, he found that fifty percent of all modifications in Chief Naval Education and Training Support's field organizations were for software.

An outstanding characteristic of every complex military system is long life. Software maintenance for these systems is costly, but failure to plan for this item can result in inflexible hardware, incapable of being modified to fill new system requirements, thus shortening useful life.

HARDWARE DEVELOPMENTS AND SOFTWARE IMPLICATIONS

The DOD has supported the increasing use of large-scale microcircuitry to improve system reliability, reduce life-cycle costs, and to achieve systems with expanded capability. Only recently, however, have large-scale integrated (LSI) microcircuits influenced the design of training devices.

Microcomputers have generally decreased system development time (over hardwired systems) and increased system reliability (due to fewer parts and fewer interconnections and high reliability of the microprocessor itself). Also, these LSI chips are cheaper than minicomputers, as well as being smaller and more flexible.

One disadvantage (or advantage) of the use of microprocessors is that the designer must understand the relation between hardware and software. In addition, modifications to software will require special skills. This is somewhat similar to the early days of computer design when the programmer had a part in building the machine.

It has been predicted (13) that the cost of computer hardware for training devices would decrease as microprocessors assume more functions. Historically, each new generation of computers has had capabilities that far surpassed the previous generation. Microprocessors are continuing this trend, and even direct compilation of code may soon be common.

Such advances will undoubtedly reduce the cost of software, but software costs and especially software maintenance will likely continue to be a major part of systems life-cycle costs. Thus, control of software life-cycle costs continues to be an item of major concern.

CONTROL OF SOFTWARE COSTS

Within the training device community, there has been no "standard" system. Both hardware and software were designed for a specific application. Severe timing constraints and the requirement for real-time interaction with the external environment originally necessitated the use of assembly language in real-time simulation. Work toward standardization has been initiated.

Recently, NAVTRAEQUIPCEN adopted a standard high-level language (real-time FORTRAN) for use in training devices. The use of higher level source language will mean more reliable programs, ability to write structured programs and fewer opportunities for errors. In addition, program maintenance should be simplified and correcting errors and adding enhancements can be better documented and easier to debug.

In order to reduce the time required for software maintenance, software engineers should be provided facilities to simplify testing and

modification of operational programs. This might take the form of immediately accessible time-sharing terminals, capable of accessing programs stored on disc in a large computer institution. This would speed up the process of debugging any errors that might occur, and also permit the training to be increased to the highest fidelity in a reasonable amount of time.

Vendor supplied software is an item NAVTRAEQUIPCEN has no control over. It is expensive and time consuming when operating systems and compilers, and the utility programs do not work as expected. When contractors modify operating systems for their particular application, NAVTRAEQUIPCEN's extensive use of cross assemblers is temporarily rendered ineffective. The acceptance of these systems must be based on more intensive and effective test procedures.

Control over software is essential. Frequent modifications to meet new operational requirements require good documentation. Accurate complete documentation is vital for software configuration control and maintenance throughout the system's life. Modifications without this documentation are expensive, if not impossible.

Training of software personnel is a relatively inexpensive area with good returns. As microprocessors become more widely used, consideration must be given to preparing the software staff for modifications and maintenance of microprocessor software. Personnel costs are high but highly trained software personnel can be an effective cost-control factor.

CONCLUSIONS

Design concepts such as system redundancy, in addition to testing and conditioning (burn-in) of IC's, circuits, and systems, have resulted in hardware systems that meet the reliability requirement of long life and mission-critical aerospace military systems. This reliability became a function of cost and profit. Similar effort must be applied to the software for training device computers. Unfortunately, there is little of the engineering discipline that is characteristic of hardware design in the software area.

Hardware design has involved compromises between many alternatives. Sufficient data are available to optimize specific characteristics which determine maximum efficiency, minimum costs, and minimum weight. This type of data is not available for software.

The life-cycle costs of software have been too long ignored. The problems involved in estimating software production costs must not be allowed to prevent progress in estimating software life-cycle costs. Although there is little historical data available on the cost of software maintenance and enhancement, it is not too late to start the development of a data base in this area.

A large part of training device costs are expended on software. Although the development of software is a high-cost item, the maintenance and enhancement of software is a long-term, high-expense item throughout the system's life cycle.

As with any system, efforts at conservation must be applied to the higher cost areas to be fully effective. In the field of training devices, it is software and software maintenance that is the high-cost item. In this era of limited budgets and increasing inflation, effort must be diverted towards predicting and controlling software costs.

Control of software costs must include prediction of high-cost areas. These are the phases that significantly influence the cost of support over the life cycle of the system. Cost control reduction and prediction is most important. Examination of alternative support concepts and taking advantage of flexibility in design of support systems is a necessity. Cost control can also be affected through reducing mistakes that result in large costs.

Effort expended in determining software life-cycle costs will aid in support planning, identifying high-cost areas, and open the door to more effective software maintenance and enhancement.

BIBLIOGRAPHY

1. AIAA Conference on Software Management, Washington: American Institute of Aeronautics and Astronautics, 1977.

2. Boehm, Barry W. "Software Engineering," IEEE Transactions on Computers, (Dec 1976), pp 1226-1241

3. Department of Defense, Casebook Life-Cycle Costing in Equipment Procurement Publication LCC-2, 1970

4. Farr, L. and B. Nanus., "Factors that Affect the Cost of Computer Programming," Technical Documentary Report No. ESD-TR-64-448. Electronic Systems Command, United States Air Force, 1964.

5. Fisher, David A., Automatic Data Processing Costs in the Defense Department, Arlington, VA: Institute for Defense Analysis, 1974.

6. Kirby, George T., "Digital Computers in Training Devices: Trends and Forecasts"

Tenth NTEC/Industry Conference Proceedings, Orlando, FL, 1977, pp 261-270.

7. Lientz, B. P., E. B. Swanson, and G. E. Tompkins, "Characteristics of Application Software Maintenance," Communications of the ACM, Vol 21, No. 6 (June 1968), pp 466-471

8. Liv, Chester C., "A Look at Software Maintenance," Datamation, 11 (Nov 1976), pp 51-55

9. Naval Postgraduate School. Proceedings: Symposium on the High Cost of Software, Monterey, CA, 1973

10. Riggs, R., "Computer Systems Maintenance," Datamation, 15 (Nov 1969), pp 227-235

11. Rotherg, Brian, Installing and Managing A Computer System, London: Business Books Limited, 1968

12. Swanson, E. B., "The Dimensions of Maintenance," Proceedings 2nd Conference on Software Engineering, (Oct 1976), pp 492-497

13. White, Gerry C., "Impact of Microprocessors on Training Devices," Tenth NTEC/Industry Conference Proceedings, Orlando, FL, 1977, pp 293-296

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INSTRUMENTATION SUPPORT FOR EVALUATING MILITARY EXERCISES

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SUMMARY

A feasibility study of low-cost feedback information mechanisms for Multiple Integrated Laser Engagement System (MILES) was conducted at University of Central Florida. An optimum mix between man and machine was the approach used in the analysis and design of the proposed system. System includes mechanisms for data collection, analysis, and displaying information for exercise evaluation. Instrumentation includes hand-held terminals, central computer, and the necessary man-machine interfacing software and devices. In addition to feasibility and cost, system compatibility with more sophisticated follow-on systems was also considered.

INTRODUCTION

Military ground engagement exercises are structured to simulate battle field conditions. Every aspect of the training exercise is directed towards achieving realism and credibility. The more realistic the simulation, the better it is in producing higher tactical proficiency levels for individual soldiers and units.

Arbitrary casualty assessment systems based on probability tables or the subjective opinion of controllers (people who oversee the exercise), have not created the desired effect. For a casualty assessment system to work, it must be realistic; i.e., soldiers must believe that the casualty assessment method used accurately reflects their performance. To satisfy this objective, casualty assessment must be related to the ability of soldiers and crews to use their weapons.

The training methodology for tactical field exercises involves two opposing forces and a team of controllers (observers). The number of controllers depends on the size of the forces (Platoon, Company, Battalion, Brigade, or Division) and the training system used.

In general, the following activities take place during any ground engagement exercise, and in the following sequence:

1. Unit trainers develop a tactical scenario based on a certain mission (choice of terrain, the opposing force size, and the type of weapons employed).
2. The units (infantry, vehicles, controllers) and the terrain are prepared based on the training system requirements.
3. The exercise is conducted with "simulated" firing and casualties.
4. Following the engagement, troops are assembled for an After Action Review (AAR). The discussion, guided by the senior controller, reviews the battle chronologically, focusing on each action in which casualties occurred. During the AAR the benefits of the exercise are assessed with respect to the strategies and tactical training. An information system (data gathering and processing) is needed to reconstruct the battle during the AAR.

ENGAGEMENT TRAINING SYSTEMS

In the past a training system called REALTRAIN [5] was used for tactical training for combined elements. The system works as follows: After trainers develop a tactical scenario, optical devices, telescopes or plastic sighting plates are mounted on or in weapons, tanks, etc., of the two opposing unit forces. These devices are aligned with the weapon sights, allowing controllers to see the same sight picture as the gunners, and permitting them to verify a gunner's aim during target engagements. Gunners "shoot" at targets by announcing an identification number worn by soldiers or displayed on vehicles while the target is aligned in their sights. The controllers verify the aim, and award "hits" or "misses." Hits are reported on a casualty assessment communication network to the controller assigned to the target engaged, who determines the damage caused by the firing weapon. The amount of damage is determined according to a set of rules for engagement based on the relative firing power between the engaged units. During the AAR, the soldiers themselves describe how they were able to engage and destroy a target, or were "killed" themselves.

Among the limitations of REALTRAIN is its dependency on controllers in assessing the casualities, which requires about as many controllers as there are participants

(infantry men, vehicles, tanks, etc.). This makes it only usable for small sizes of opposing forces, with damage assessment based on controller judgement.

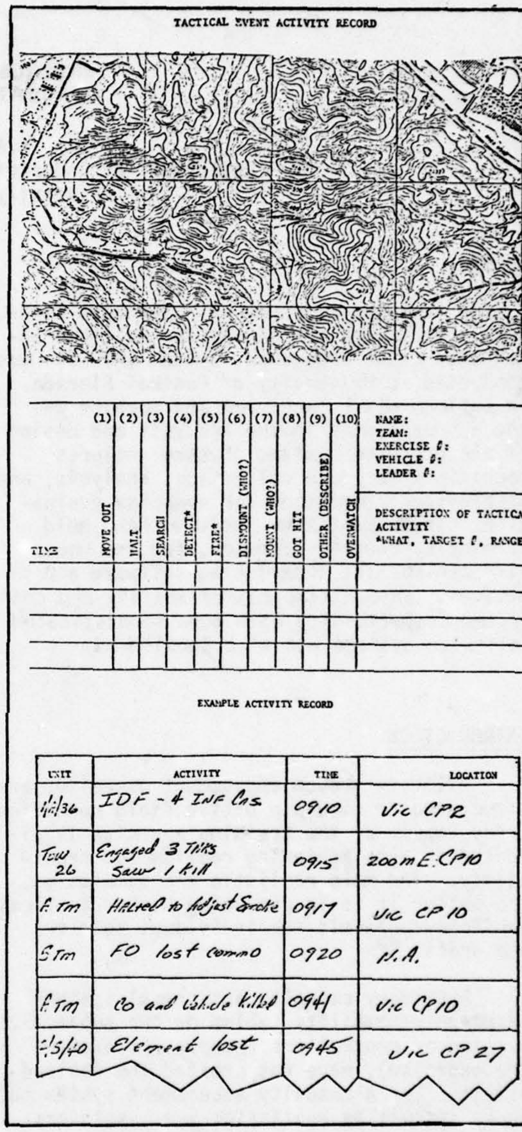
A major disadvantage of REALTRAIN is, in spite of large numbers of controllers, the battle can never be reconstructed in the AAR on a battalion level due to lack of information (positon/time, and who killed who).

A new battle simulation technique developed recently avoids many of the disadvantages in REALTRAIN. The technique uses "safe laser" guns and mounted detectors to simulate the firing and the hit during the exercise, making the battle almost realistic in this regard. The technique is used in a training system called Multiple Integrated Laser Engagement System (MILES) [4]. The system is designed in a way that it automatically assesses casualties with a great degree of realism. Each weapon (rifle, tank, etc.) is equipped with a mounted laser gun which duplicates the effective range and power of the real weapon. Each vehicle, tank, soldier, etc., is equipped with a set of laser detectors in the critical location of the unit. When a unit scores a "hit", the casualty is assessed by disabling the "destroyed" unit laser guns and activating a smoke bomb signaling a visual kill. This automation of the real-time casualty assessment eliminates the controller's role in this event, and reflects with precision the range and firing powers of the engaged units.

PROBLEM STATEMENT

The use of lasers make it possible to simulate battles on a battalion, or even a brigade level. On the other hand, an AAR--where the battle is reconstructed and military techniques are discussed--would be impossible to conduct without an information system that would record the events of the battle as they develop. The characteristics of such a system include the ability to collect information on a real-time basis leading to the determination of "who killed who, when and where."

The existing information system in MILES uses human controllers as the primary means of data collection. This operation is done by completing data forms (Figure 1), and reporting it on a communication network to a Central Control. The system uses a large number of controllers/collectors. Table 1 lists estimated manpower for different levels of training exercises. Operational costs as well as manpower allocation is extensive.


TACTICAL EVENT ACTIVITY RECORD

TIME	(1) MOVE OUT	(2) HALT	(3) SEARCH	(4) DETECT*	(5) FIRE*	(6) DISMOUNT (WHO?)	(7) MOUNT (WHO?)	(8) GOT HIT	(9) OTHER (DESCRIBE)	(10) OVERWATCH	NAME: TEAM: EXERCISE #: VEHICLE #: LEADER #: DESCRIPTION OF TACTICAL ACTIVITY *WHAT, TARGET #, RANGE

EXAMPLE ACTIVITY RECORD

UNIT	ACTIVITY	TIME	LOCATION
1/c/36	IDF - 4 Inf Cos	0910	Vic CP2
Tow 26	Engaged 3 Tnks Saw 1 kill	0915	200m E CP10
F Tm	Halted to Adjust Smoke	0917	Vic CP 10
S Tm	FO lost commo	0920	N.A.
F Tm	Co and vehicle killed	0941	Vic CP10
1/3/40	Element lost	0945	Vic CP 27

Figure 1 - Operational Data Collection Forms in MILES

Table 1

COLLECTION MANPOWER ESTIMATES FOR MANUAL DATA COLLECTION ON DIFFERENT LEVELS OF ENGAGEMENT SIMULATION (E/S) [1]

Level of E/S	No. of Collector-Controllers	Est. Operators of Networks
*Platoon	85	3
*Company	170	6
*Battalion	298	12
*Brigade	600	24
*Division	1190	48

The purpose of this paper is to present a feedback information system for MILES which uses an optimal mix of man and machine to collect data necessary for a MILES after action review, where computer plays a major role in completing, processing and presenting the data.

ANALYSIS AND DESIGN

Data Type

The data required for the AAR can be grouped in terms of two categories.

- Planning data (e.g., geographical boundaries of the exercise; instructions to participants)
- Process data (e.g., timing and events during the engagement exercise)

Planning data can be determined prior to and at the start of the exercise from commander/leader and collected via their oral, written, and drawn operations orders. Process data is the most difficult to observe and collect. Process conditions, events, must be sensed with only minor control/monitoring intervention and collected without exercise disruption. Process data can be defined for each participating unit as the following:

- Position time data
- Direct fire exchange data
- Indirect fire exchange data
- Casualty data
- Battalion command and control

When combined with planning data, these elements of process data will form the source and cross-checks for all outcome data required in the AAR to reconstruct the battle.

SYSTEM DESIGN

Along with the minimum data required defined previously, three main constraints were defined prior to the analysis and design. These constraints are:

1. Cost Constraint: The cost of any data collection mechanism should not exceed $200,000 for a battalion level.

2. Time Constraint: Battle analysis and data for AAR should be ready for demonstration within 30 minutes from the completion of the exercise.

3. The transition from the existing manual system to any proposed system, as well as the transition from the proposed system to any future more sophisticated system, should be smooth; i.e., only improvements over the current systems towards automation.

Subject to these constraints, sophisticated tracking and fire detection mechanisms are too expensive. A mix between contollers/collectors and instrumentation support is the chosen approach.

The suggested system is composed of three phases:

1. Data collection
2. Data processing
3. Data management, display and presentation

In the first phase, a set of human data collectors would send real-time data over a radio network to a central computer (Figure 2).

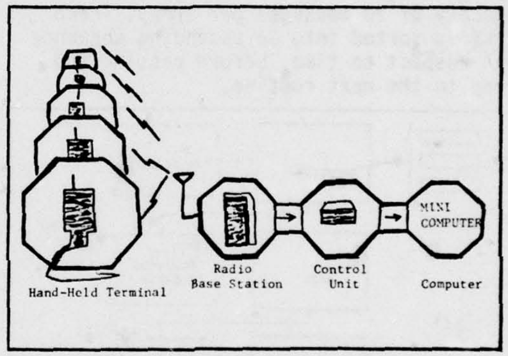


Figure 2 - Data Collection Mechanism Network

Controllers use hand-held terminals in relaying compact messages describing the event. It is estimated that one controller using a hand-held terminal can cover the events of five participating units. The message contents are as follows:

- Controller identification code (could be built in)
- Unit number or code
- Action description code (firing vs hit)
- Unit location coordinates (approximate)

Message items are either preceded by a key word or according to a predetermined sequence. The software would be designed in a way tc minimize the redundent information. Based on an average of 20 events per unit per battle, a maximum of 4000 messages could be relayed to the central computer for an engagement on a battalion level (200 participating units).

The second phase is a processing phase (Figure 3) where the central processor will receive the data messages and pass them through two routines.

1. Message validation and completeness routine (COMPLETE): Its function is to validate the message against a set of rules related to the exercise, and to complete the data messages with necessary information.

The message would be completed to contain the following items:

- Time of message
- Controller number
- Unit identification number
- Action (Fire/Hit)
- Unit type
- Unit team
- Firing range and effect
- Unit location

Time is added to the message as it is relayed through a built-in clock (set to zero at the beginning of the exercise).

Unit type, team, and firing range are added through accessing a unit specifications file, with a record for each participating unit, and using the unit number as its access key. Messages are stored in 3 arrays with a capacity of 20 messages per array. Each array is sorted into an ascending sequence with respect to time, before passing the array to the next routine.

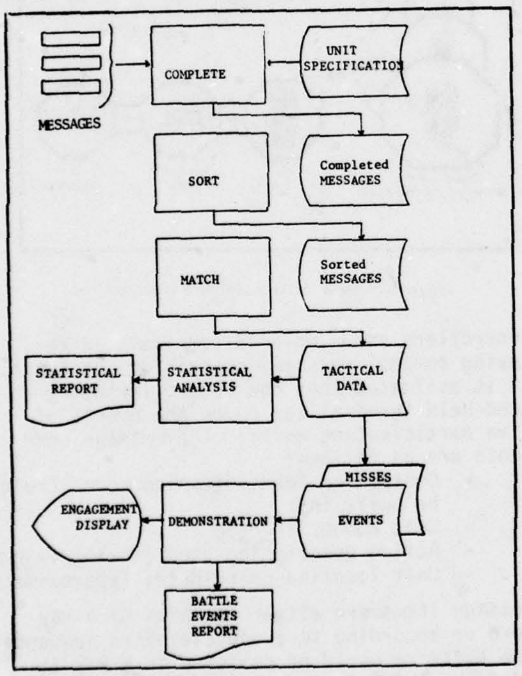


Figure 3 System Block Diagram - Processing Phase

2. Matching messages routine (MATCH): This function is to determine the "hit event". Messages within the same array are matched according to their times. The following rules coordinate the match:

a. Time is computable within $\pm$ limits
b. Units are of opposing teams
c. One unit action is fire while the other is hit
d. Units in the two messages are within the range of firing of the fire unit
e. The hit of killed unit should be within the killing "spectrum" of the firing unit

Two messages match if they meet at least the first 4 rules, since the fifth can be programmed in the laser software. A match would result in the creation of an "event" record, that would be output to an "EVENTS" file. The file would be used in reconstructing the battle in the AAR. The event record has the following information:

- Time of kill
- Unit fired
- Unit killed
- Position of firing unit
- Position of killed unit

Events will be recorded in chronological order. The maximum size of the EVENTS file will be 200 records for a battalion level exercise.

Other output files from the matching run are a "MISSES" file which records all units which fired and missed, with their respective time and location. A statistical data file could be produced containing data pertaining to the exercise to assess the practice in a sequence of engagement exercises.

The third phase involves data management, display formatting, and storage. The vast majority of planning data will be collected in manual form and, therefore, will require data management in at least its first stage of handling. As for the data analysis and reconstructing of the battle, it is subject to computer versus manual trade-off decisions. The EVENTS file would be used to output the events in a printed list that can be used to back up reconstruction of the battle on a three dimensional scaled map or to display the battle on a CRT screen superimposed over a background map.

Regardless of the demonstration method, each unit commander specifies his path, and with the aid of the events report, facts are demonstrated to the participants with alternative actions suggested.

HARDWARE CONFIGURATION

Based on an engagement exercise on a battalion level (200 participating units), a total of 25 controllers/collectors are estimated requirement for both enforcing the rules of engagement, indirect fire assessment, and data collection.

Basic hardware requirements [2] include the following:

- Mini Computer, with no less than 64 k Byte memory, portable, and interfacable with peripherals.
- Photo enlargement map system and material support.
- Peripherals include: Printer, disk unit, and a CRT.
- Hand held terminals (25 on a battalion

level) with a radio network to the central processor.

Software requirements include programming of the previously described logic. It is estimated that the cost of the system lies within the cost limit specified previously. Since the original project included studying all the potential state-of-the-art equipment, other systems were also investigated. Table 2 is an outcome of comparison between investigated systems (estimated costs are not mentioned). For more details refer to [2] where other factors such as cost, accuracy etc., are included.

TABLE 2
INFORMATION FEEDBACK SYSTEMS AND THEIR DEGREE OF AUTOMATION

	TYPE OF SYSTEM COMPONENTS			
Degree of Automation	Data Collection Method/Equipment	Approximate No. of Controllers	Data Processing Equipment	Data Display Equipment
Manual	1. MILES equipment with form and manual data collection	160	Network operators-manually match events	3 dimensional demonstrates manually displayed with models
Semi	2. MILES equipment with hand-held terminals	90	Mini Computer, and compatable prepherials (printer, disks)	Graphic projection on screen/or events report
Semi	3. MILES equipment with voice entry system	30	Mini Computer and compatable prepherials (printer disks)	Graphic projection on screen/or events report
Fully	4. Range Measurement system (General Dynamics) with modified MILES equipment	20	Compatable equipment to the Data Collection	Graphic projection on screen/or events report
Fully	5. Position locating and reporting system (Hughes) with modified MILES equipment			
Fully	6. Global Positioning System (SAMSO)			

SYSTEM IMPLEMENTATION

The described system is considered the first step to instrument the purely manual data collection and information system for MILES battalion exercises. The system currently in use is operated on a manual basis, where controllers report messages verbally over a radio network to a central command. Another team of controllers perform the matching operation (processing). Matching is time consuming and so far has only been implemented on a company level with a total of about 20 units participating in the exercise. The transition from manual to man-machine mix should be smooth, since the logic of the operation is the same. The number of controllers could be reduced with proper training on the usage of hand-held terminals. A more sophisticated system could use a voice data entry devices [3] in place of the hand-held terminals as input to the system. Such transition should also be smooth since the software will not change.

CONCLUSION

MILES as an engagement exercise is successful. The pace by which battles are conducted as well as the casuality assessments are on a real-time basis. Instrumentation of the accompanying data gathering system is essential on a battalion level to gain full credibility of the exercise during the AAR. A semiautomated system is suggested here to be the first step towards complete automation. The system uses an optimal mix between man and equipment. It is theoretically feasible; however, it needs simulated laboratory testing and experimental justification. The system is flexible to accept new technologies in data gathering and processing without major changes.

ACKNOWLEDGEMENT

The original research upon which this paper is based was sponsored by the U.S. Army, Program Manager for Training Devices (PM TRADE), Orlando, Florida. The authors would like to particularly acknowledge the assistance of Dr. R. Hofer, Mr. P. Wampner, and Mr. L. Fisher of PM TRADE, Dr. D. Hansen of Human System Integrated, Inc., (El Paso, Texas) and Col. L. Word of the U.S. Army Training and Doctrine Command (Ft. Eustis, Virginia).

REFERENCES

[1] Duncan N. Hansen, Paul R. Drewfs, Engagement Simulation (E/S) Instrumentation Allocation, Science Applications, Inc., Technical Report, 1978

[2] Darrell G. Linton, Yasser A. Hosni, Potential Manual/Instrumentation Requirements to Support MILES Battalion Level Exercises, Technical Report, U.S. Army (PM TRADE), Orlando, Florida, 1979

[3] Intelligent Voice Data Entry System, Technical Specification, Interstate Electronics Corporation, Anaheim, California

[4] MILES: Field Training with Realism, Xerox Electro-Optical Systems, Pasadena, California

[5] Tactical Training for Combined Arms Elements, REALTRAIN, U.S. Army Armor School, ATSB-DT-TP, Fort Knox, Kentucky, January, 1975

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COMPUTER AIDED SYSTEM FOR THE DEVELOPMENT OF AIRCREW TRAINING (CASDAT) A GENERIC APPROACH TO COST-EFFECTIVE ISD

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Veda Incorporated

INTRODUCTION

The effectiveness of current instructional development systems in the military cannot be argued. Unfortunately, neither can the great cost of the formal procedures used to design such systems. Instructional systems development (ISD) has expanded in scope during the past few years as ever-new applications are found for this approach to training design. More recent, however, are cost-reduction efforts in the form of automated aids to the ISD process. These aids include computerized systems for developing task lists, for writing behavioral objectives, for structuring syllabi, etc., and they vary in terms of their complexity, cost, and the extent to which they assist the ISD developer to create and then manage his instructional program.

Veda Incorporated is presently under contract to the Naval Training Equipment Center (NTEC) to design and implement one such automated aid for the development of aircrew training. This system, Computer Aided System for the Development of Aircrew Training (CASDAT) will be described in this paper, with an emphasis on the unique, generic feature of the underlying task model. This generic structure applies across all types of aircraft, missions, and flight crew positions, and possesses several important advantages for instructional development, management, and research. Having taken the step to automate the methods of ISD, it appears to be time for examining these methods to establish just what it is we wish to automate.

BACKGROUND

The CASDAT system began as an effort to assess the feasibility of automating steps of the ISD process with the use of data bases, taking advantage of existing aircrew training programs to provide inputs into new programs. Present ISD methods for the military are prescribed by instructional documents specific to each service; MIL-T-29053 stands as the Navy guide, although procedures are parallel for all ISD efforts. Each development project begins with a task analysis, or description of activities for the job being trained. This resulting task listing is then converted into statements which can be used to establish instruction, called behavioral objectives. These objectives are then clustered systematically into instructional units which are then arranged into a syllabus, and appropriate media are selected to form the training materials of each lesson. Finally, each lesson is arranged into a logical flow of events by writing a lesson specification, leaving actual creation of instructional materials and lesson authoring as the final phase of the development effort.

How could data bases help to abbreviate the time and resources needed for these steps? The Veda project began with a comparison of existing programs, step by step, starting with task listing documents. One observation was immediately clear: although every ISD program had ostensibly referred to the same MIL-T specification, none of the resulting lists looked similar, even for closely related aircraft (e.g., F-4 and F-14). The original intention had been to identify similarities--or "links"--between parts of existing ISD programs and to use them as organizational rules in a data-based system. Obviously, these documents had to be made comparable if any such links were to be found. For this reason, the Veda project staff proceeded to force comparability by an analysis of underlying structures in the task listings.

The first point of correspondence between ISD documents was found by conducting a "syntactic analysis" of individual task statements. Basically, this involved a reduction of each statement to its fundamental parts, without consideration for differences in sentence style or needless specificity; a task such as "preflight engines" has a precise meaning to a helicopter, prop, or jet pilot, although there is nothing in the statement itself which is so specific that it cannot be used in all three task lists. A great many tasks were thus found to be quite common across all types of aircraft.

Once the task statements were converted in this way, a common task structure was simple to establish. This was, really, an averaging operation, picking and choosing the best or most common task arrangement rules from the available documents. Again, a structure was fashioned in this way which could accommodate all types of aircraft--a "generic" task listing. A sample of this listing is displayed in Figure 1.

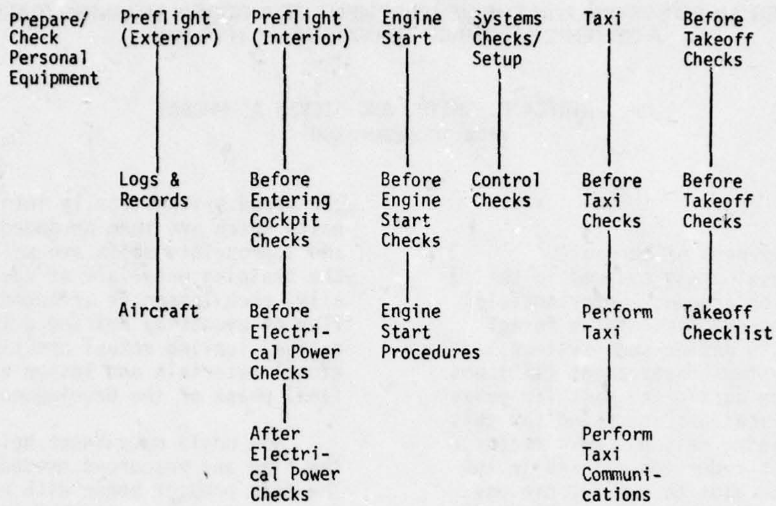

Figure 1. Generic Task Listing - Prelaunch

It was apparent that additional work would be necessary to expand this generic listing, but a tool was available, even at this stage of the project, which could be used to compare training programs across the aviation community, a conceptual "axis" for aircrew ISD.

FINISHING THE TASK MODEL

Now, the task listing was not much use in its original form for any particular aircraft, but aircraft could not be compared productively. Could links, or task families, be determined from further analysis of ISD documents which had been converted to this common structure? This was, in fact, the case. Tasks were found which fell into groups, depending on what dimension was being examined. Task listings, for example, of aircraft which carry ordnance were found to contain specific steps regarding the mission planning for that ordnance, the preflight for the ordnance, the arming and use, and procedures for recovery on land or ship with hung/ unexpended ordnance. If any ordnance at all were carried by a particular aircraft, then certain tasks must follow. Furthermore, if the specific type of ordnance were known, additional tasks could be identified which were part of this "family" (e.g., some missiles can only be used in an air-to-air role, while others can also be employed against surface targets; thus, a missile in the latter category would bring additional mission tasks into the family). A set of sixteen such dimensions was found to be the most productive for defining task families. This set was later refined to eleven, with further modifications possible. The strategy which resulted from this approach was one of selecting relevant dimensions from the set, based on known aircraft characteristics, and appending the associated task families to the original generic listing. When this approach was exercised for several existing aircraft, it was found capable of generating approximately 75% of the tasks found in the ISD task listing--generated by traditional methods--for each. This validation of our method was applied to all types of aircraft (jet, prop, helicopter), most major tactical missions (e.g., fighter, attack, anti-submarine warfare, search and rescue, etc.) for all branches of the military services. Although this 75% figure is rough, due to the analysis time available for data collection in this phase, the result is very encouraging. By way of illustration, Figure 2 shows a sample of the task listing which was generated for the F-18, using this method. The tasks are not identical to the original document (using traditional ISD procedures), but are at least their equivalent.

COMPLETING THE CASDAT SYSTEM

An initial formulation of a task listing data base has been described, using a generic task listing structure and data organization rules which correspond to aircraft characteristics (i.e., the dimensions discussed in the previous section). Obviously, a task listing which represents only three-quarters of the activities which really occur is not a satisfactory tool for developing a complete instructional program, so a tutorial device was included to guide the instructional designer through the process of finishing the task list. The CASDAT system currently contains

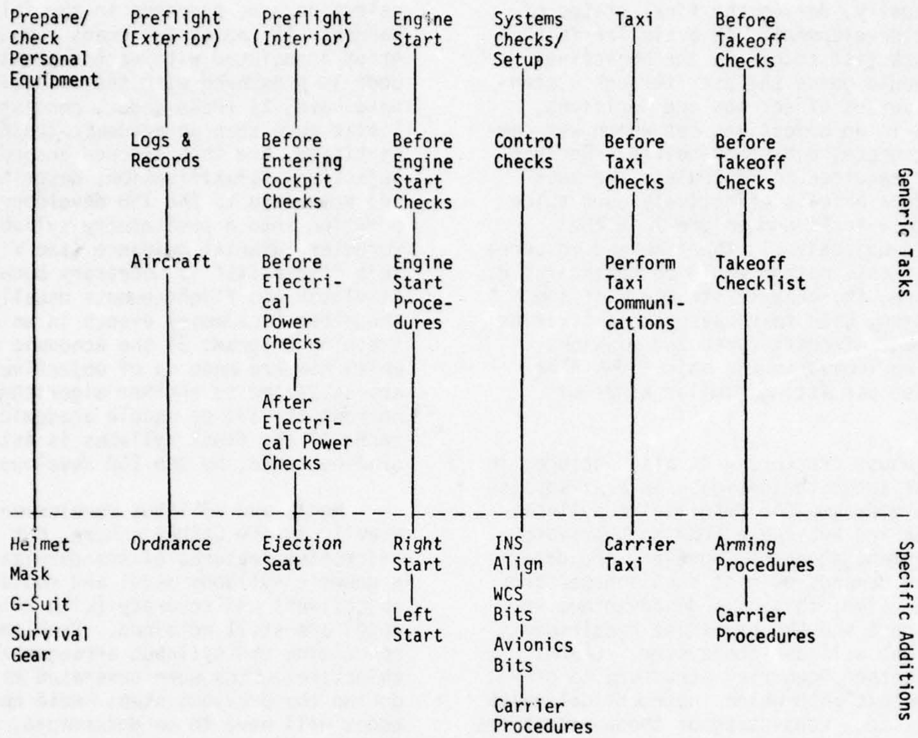

Figure 2. Task Listing for F-18.

a preliminary plan for an interactive computer program which assists the user in authoring those additional tasks which are too aircraft-specific to be generated in any other way. Exact features of this program are not defined at this time, but the tutorial package is intended to control: 1) the standardization of the remaining tasks, in that they must be compatible with the pre-existing list structure created by CASDAT, 2) the accuracy of the remaining tasks, because they should conform to the guiding ISD principles of the particular branch of service, and 3) the thoroughness of the tasks, to insure that all activities performed by the flight crew are reflected explicitly in the final task listing. All of these factors can be placed into computer formats, and current efforts are being directed at establishing the minimal amounts of information, which must be provided to the ISD designer at critical decision points, to build the least expensive tutorial program capable of achieving high-quality results.

CASDAT APPLICATIONS FOR OTHER ISD STEPS

Five primary steps for instructional development were mentioned previously. Automated aids for each one are presently being designed by the Veda staff, for implementation with the generic task model, and will be summarized here. It is important to note that several private companies and some governmental agencies are also involved in the creation of automated aids to ISD. The founding concept of the CASDAT system, however, is the generic treatment of the job category for which instruction is being developed. The advantages of this approach for training design, management, and research will be discussed at length in subsequent sections of this paper.

Once the task analysis is complete, behavioral objectives must be fashioned as the "raw material" for lesson development. Because the CASDAT system employs a generic task model, together with prestored families of tasks, creation of an objectives hierarchy is a simple process and takes place simultaneously with the establishment of the task list. An objectives data base is proposed with this system, which maps each element in the task listing base to a group of behavioral objectives. Thus, when appropriate tasks are assembled and organized during the first step of the ISD process, relevant objectives are also loaded and organized for the second step. A special-purpose tutorial program would need to be included for this phase of development, as well, in order to insure that all required objectives were included for the selected tasks, and that appropriate objectives could be authored for tasks which were

added manually, during the final states of task list development. In a similar fashion to the task list tutorial, the objectives program would guide the user through a standardized series of actions and decisions, resulting in an objectives set which was complete, accurate, and standardized. Because the labor required to manipulate the task listing data base is effectively used twice (to assemble tasks and to pre-load the associated objectives), the time and resource savings of this method would be considerable. Furthermore, the generic structure of the task listing, used to compare the activities of different aircraft types and missions, would be reflected in the objectives hierarchy, thus permitting similar kinds of analyses.

Syllabus structuring is also included in the CASDAT automated design. Several sophisticated algorithms for determining syllabus sequencing are available from both private and government agencies, however, the data processing demands of most such schemes are quire extensive; this is a disadvantage in terms of cost and the expertise requirements of those who will use the system. CASDAT employs another "generic" structure to provide a context into which instructional units will be fitted, consisting of those attributes that are common to all training programs. Basic aircraft systems instruction, for example, always precedes weapon system instruction; basic flight operations precede tactical flight operations; flight simulation events precede applicable flight events and, in turn, both are preceded by academic instruction.

CASDAT is being designed to stratify the results of the objectives-formulation step, ordering these objectives in terms of the complexity of intellectual skills underlying each. This sequencing of objectives forms the initial output of the syllabus operation; before the objectives can be partitioned into lessons and incorporated into the syllabus structure, the data is subjected to a media selection algorithm, which determines a subset of available media which could be used to effectively instruct the particular objective.

The CASDAT algorithm is, again, more simple and straightforward than some other selection schemes available. The special demands and constraints of each instructional design program are considered sufficiently unique to make the use of a more sophisticated algorithm unattractive as an automated aid to ISD. The products of such algorithms are, furthermore, usually quite vague, the result of a weeding-out procedure which yields a group of media candidates and not just one or two choices. Thus, the CASDAT output compares favorably with more complex methods of selection, and proceeds in the following manner: 1) the system scans a media code group associated with each objective. This code is prestored with the objectives in that data base; 2) these codes, consisting of little more than an academic-trainer-flight partition, are then grouped according to the objectives stratification, described earlier, and presented to the ISD developer for incorporation into a preliminary syllabus, under computer tutorial guidance (see Figure 3). This "first-fit" is necessary because the simulator and flight events usually drive the other (academic) events in an aircrew training program; 3) the academic events, which now are made up of objectives groups, are subjected to another algorithm which narrows the set of usable academic media for each; 4) the final syllabus is established, or fine-tuned, by the ISD developer.

Media and syllabus development interact heavily in the CASDAT scheme, but the initial attractive features of standardization (with a generic syllabus model and media codes for objectives) and accuracy (with tutorial guidance) are still retained. Problems remain concerning the syllabus arrangement of those objectives which were generated manually during the previous step; media and skills codes will have to be determined, in some fashion, for each. Expansion of the tutorial programs is currently viewed as the best solution to these problems.

Little is currently envisioned for automated aids for lesson specification development under the CASDAT scheme. Unless costly computer systems are employed--a major pitfall of any automated aid design, which is intended to <u>reduce</u> the costs of current ISD methods--the benefits of CASDAT fall into the area of providing the instructional designer with a convenient presentation of information in order to facilitate his manual authoring efforts. Thus, an objectives list could be offered for the lesson under development, together with appropriate page headings and other "secretarial" services. A finishing program is an additional possibility, offering the developer a set of reminders to check the format and comprehensiveness of his work. The design of this portion of CASDAT is still in an early stage.

AUTOMATION BENEFITS OF CASDAT

The motivation for designing automated aids to ISD is primarily one of cost. Current manual methods are very time-consuming and require personnel trained in ISD principles. These methods are, furthermore, redundant: similar work is done whenever a new program is initiated <u>and</u> ISD products (e.g., objectives) must be used repeatedly within a program, creating a tracking or "bookkeeping" problem due to volume. Automated aids,

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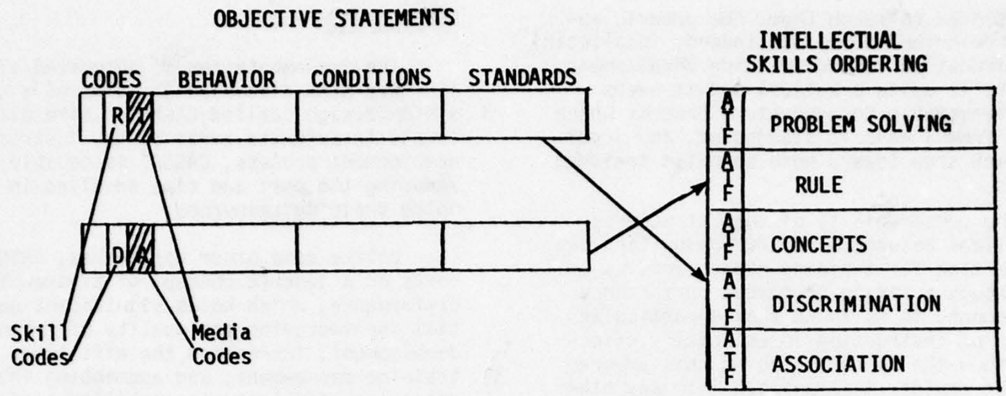

Figure 3. Media and Syllabus Operations

including CASDAT, contribute greatly to cost reduction by: 1) accessing, organizing, and displaying required information quickly. Automated aids can manipulate large amounts of data rapidly and accurately, while keeping track of the progress of those manipulations; 2) contributing to the decision-making process with automated development strategies. By taking over some of the technical planning duties, automated systems can be designed for use by relatively untrained personnel; 3) making available the products of previous, relevant training programs. By making use of what has already been done (and stored in a data base), the ISD process is abbreviated to those steps which are unique to the current project.

GENERIC BENEFITS OF CASDAT

So far, the CASDAT system shares the advantages of other automated ISD aids or designs. An important difference, however, is that the CASDAT scheme is founded on generic models of both the job to be trained and (to a lesser extent) the syllabus used to train it.

A generic task structure for a job or class of jobs reduces the data handling requirements for an automated system; large groups of tasks, including the basic generic model itself, are accessed in an all-or-none fashion. This reduces the demands on the ISD developer considerably by presenting him with the major part of his task listing immediately and providing him with a context in which to fit remaining, specific tasks under tutorial guidance. The system is, likewise, not required to handle the construction of each individual task, but only those which are needed to complete the last portion of the list, thus reducing the minimum cost of processing software.

A generic task or syllabus model maintains the quality standards of the final products by insuring that certain ISD principles are observed. In this case, decisions regarding the task hierarchy, task statement format, numbering or coding systems, and syllabus development strategies are implicit in the model and not subject to the diverse interpretations of ISD designers. The result is a consistent product, in keeping with the policies of instructions such as MIL-T-29053. By reducing the need to make key ISD decisions, these generic models confine the design effort to those aircraft-specific areas which can be best handled by subject matter experts; in most cases, such personnel (e.g., flight instructors in training squadrons) are less expensive resources to employ in a design effort.

It was mentioned earlier that the generic aircrew model forms an "axis" around which different flight jobs can be compared. This is because the tasks involved in the listing proceed from those which are common to all aircraft, through those which are defined by discrete dimensions of equipment or mission, to those which are unique to a particular aircraft. What this means is that many of the differences between training programs--based on their respective task listings--are unnecessary, that training need only differ where a definable dimension separates task families between aircraft. The cost savings from this point of view of training could be quite significant. Aviation communities which share a tactical mission could benefit from a single, thorough study of the instruction required for that mission; an avionics system could be taught from a single program, disseminated to all communities which used that system; the general strategies for hovering flight could be used by all helicopter training squadrons, with specific modifications as necessary for the model of aircraft used. The military service would benefit from the cost savings of having done the instructional design only once. It is understood that there exists an interaction between a specific aircraft, a common mission or system, and the instructional

methods used to teach them; the generic approach described above is, indeed, idealistic. The orientation toward training development, however, is quite practical and it seems quite reasonable to advocate a process which begins from a generic standpoint, and justifies each step toward more specific training methods.

The comparability of task structures and syllabi between aircraft communities has an advantage for training management, as well. If, through training or combat performance measurement, it is found that a particular program of instruction is especially effective, then the concepts behind this program could be rapidly incorporated into any other training program which shared the relevant characteristics of the job under examination. Even if such a program existed presently, the analysis and instructional design changes necessary to implement the superior program into other communities would involve prohibitive costs. If the change were, in fact, incorporated for other aircraft, the differences in task models would prevent an accurate assessment of the reasons for its success or failure; the tracking tools would not be available, as they would be if both communities were working from a common task structure.

CONCLUSIONS

The implementation of automated aids for ISD have been discussed in terms of a current system design called CASDAT. Like all attempts to automate parts of the instructional development process, CASDAT is capable of reducing the cost and time involved in developing training resources.

Unlike some other approaches, CASDAT rests on a generic concept of aircrew task performance, which holds significant potential for improving the quality of training development, increasing the efficiency of training management, and augmenting the research and development capabilities of instructional analysts.

The example used for the system discussion was aircrew training. Significant new territory for generic task modelling lies, however, in the areas of maintenance training, technical training, and military "preparatory" programs (e.g., basic aviation, electronics, reading skills, etc.).

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INDIRECT FIRE SIMULATION USING REMOTELY PILOTED HELICOPTER

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ABSTRACT:

This paper is a feasibility discussion of incorporating remotely piloted helicopter (RPH) into the Multiple Integrated Laser Engagement System (MILES) Exercises so as to simulate and assess casualties of indirect fire. The paper describes existing systems and current proposals for fire in engagement exercises, the problems of compatibility between MILES equipment and RPH's. A new approach is then proposed that uses an RPH to carry a receiver/transmitter which relays the MILES code from the firing weapon onto the target.

INTRODUCTION

The Multiple Integrated Laser Engagement System (MILES) is an engagement training system which employs eye-safe lasers and microelectronics to simulate the firing capabilities of rifles, machine guns, and other direct fire weapons. Battery-operated laser transmitters, attached to conventional field weapons, allow ground troops to fire coded invisible laser pulses instead of live ammunition. Receiving detectors sense the laser pulses and instantly provide audio and visual indicators of hit or near miss. The fact that the laser transmitters have to have a line-of-sight target in order to score a hit makes it impossible to simulate indirect weapon fire. Any proposed approach must of course be compatible with currently used MILES equipment. The system should immediately assess casualties and the effectiveness of the indirect fire. This would ensure realism of the exercise. Finally any proposed system should be independent as possible of exercise controllers and umpires.

Several solutions for automating the indirect fire in MILES have been suggested. In most all the suggestions, the need for an elevated observation post is mentioned. This post would be positioned so that an umpire could observe both the firer and the target, and,consequently, he could assess the hit, missess, and casualties, etc.

Using helicopters as observation posts is not a new idea; however,it was considered by many as impractical. A full-size helicopter would require considerable coordination between umpires, aircraft control personnel, and aircraft support personnel. Also even the presence of a full-size helicopter in the air above the impending target would be an unrealistic cue that indirect fire was imminent. This would, of course, give an unrealistic advantage to the target. Also high powered, non-eye-safe lasers would be required and they can present a hazard to the pilot and other aircraft personnel aboard. This paper suggests the usage of a remotely piloted helicopter (RPH) in MILES exercises to simulate and assess casualties of indirect fire which obviates these problems.

OTHER PROPOSED SYSTEMS FOR INDIRECT FIRE SIMULATION

Current plans for MILES are to use a system very similar to REALTRAIN [4] in simulating indirect fire. The only difference is that an umpire, called the Fire Marker is armed with an umpire's control gun to designate those who are indirect fire simulation casualties. The following is an example [3] for 155 mm artillery. A 155 mm artillery piece will fire a round. A ground burst simulator will be thrown by the Fire Marker into the vicinity of where the round would have struck the ground. Casualties would be designated using the umpire's control gun employing following criteria:

(1) 0-10 meters - All vehicles and their passengers are destroyed other than those in tanks. Tanks immobilized with loss of communications and any exposed personnel are casualties.

(2) 10-50 meters - Vehicles other than tanks destroyed to include passengers. Tanks only lose communications but exposed personnel are casualties.

(3) beyond 50 meters - There is no effect.

Using the umpire's control gun requires care to avoid hitting other sensors that may be at a greater range (possibly up to 1000m) beyond the intended casualty.

As demonstrated in the example scenario, this MILES indirect fire simulation is completely dependent on a large number of controllers or umpires and the radio network connecting them with the firing weapons. The required network is illustrated in Figure 1. This system has little compatibility with the successful simulation of direct fire provided by MILES equipment. In general,this approach is cumbersome, slow, unrealistic, and difficult to implement.

A recent study [2] was conducted to evaluate alternative methods of simulating indirect fire, such as mortars and artillery, as well as area effects in general in a training engagement exercises. The study suggests the following as elements of a simulation system:

- An area-scanning laser transmitter using MILES compatible codes.
- Under-fire audio-cue device mounted on all targets and triggered by the scanning laser beam.
- An under-fire visual cue generated by a special air-burst smoke round fired by an umpire from a M-79 low velocity grenade launcher.
- A position-finder and a target locater using an observers sextant and a hand-held programmable calculator.
- A communication control center for a VHF radio control network to inform the umpires and fire markers of the intended targets.
- Shell smoke is simulated using vehicle or helicopter deployed cannisters.

Figures 2 through 5 are schematic representations of the recommended system.

INDIRECT FIRE SIMULATION USING A REMOTE PILOTED VEHICLE

Of all the physical characteristics of Laser Weapon Fire Simulation (LWFS) that presents the most difficult problem of simulating indirect weapon fire is the line-of-sight propagation of the laser light. Hence, the indirect fire simulation requires an intermediate receiver and transmitter in the signal path between the firing weapon and its intended target. Such an intermediate system is commonly known as a transceiver. This transceiver could be mounted in a flying vehicle which would hover over the designated target location and provide a line-of-sight relay for the artillery's transmitter. An example of a Remotely Piloted Helicopter (RPH) which could easily fly a transceiver for indirect LWFS, is a system WIDEYE manufactured by Westland Helicopters Limited of the United Kingdom. The RPH flying is shown in Figure 6.

WIDEYE is much smaller than a conventional manned helicopter, and it can be easily stored and transported, as shown in Figure 7. The symmetry of the helicopter, along with its simple automatic stabilizing and altitude control system, allows the vehicle to be flown easily by a non-pilot with a very small amount of practice. The small dimensions of the RPH, 1.5 meters in height and 0.75 meters in diameter, make WIDEYE very difficult to see with the eye. The attention of the eye is attracted by linear motion or other changes of scene. A small non-reflecting, low contrast shape hanging motionless or moving slowly is a difficult object to detect. Also the noise of WIDEYE has been kept to a low level by using a low rotor-tip speed. WIDEYE would be virtually unnoticeable to the ground personnel and undetectable by the firing artillery.

The RPH incorporates a navigation system which is based upon the narrow beam radio command and data links between the aircraft and its ground control station. The range of the RPH is determined by the time taken by an airborne transponder to return a coded pulse sent along the command uplink. The bearing of the RPH is derived from the position of the ground control station steerable antenna.

WIDEYE can carry a range of payloads, and the incorporation of a laser for target marking has already been briefly addressed. The WIDEYE control console for SUPERVISOR is shown in Figure 8, but for the indirect fire simulation role a much simpler console might suffice.

The transceiver system aboard the WIDEYE RPH would consist of detectors mounted around the body of the helicopter and their associated electronics as part of the payload. The detector system could be a standard MILES type LWFS detector system. The transmitter on the WIDEYE vehicle would be a standard MILES low-powered, eye-safe, laser transmitter-mounted in a down-looking position co-axial with the TV camera. This would allow the WIDEYE controller to also see the target.

The artillery transmitter would be a high powered pulsed injection laser, transmitting into wide angle beam. The weapon transmitter could be bore sighted with the weapon itself. Although we have initially described a laser transmitter, a millimeter wave transmitter might be advantageous because of the possible presence of a considerable amount of smoke from the weapon firing. A millimeter wave transmitter operating at a frequency of 94 GHz can very effectively penetrate smoke and dust as well as most atmospheric consitutents. Also this transmitter would inherently be eye-safe. If such a transmitter were to be used, the receiver aboard the WIDEYE RPH would have to use a compatible detector system such as unbiased point contact diodes as opposed to solar cells used in the MILES equipment. The down-link from the RPH, would remain laser transmitter no matter what transmitter was used for the up-link, and hence remain compatible with all MILES equipment.

The engagement scenario for indirect LWFS using the WIDEYE RPH would be as follows:

1. A forward observer would call in the target coordinates to the RPH controller.
2. The controller would then fly the RPH to a point directly above the given coordinates and with a line-of-sight to the artillery battery. The controller navigates the RPH using the radio tracking system.
3. The RPH controller then calls the artillery battery to give them the target coordinates.
4. The artillery battery then lays-in direction and elevation. The transmitter attached to the gun's barrel, is simultaneously aimed.
5. The transmitter fires a kill code in a wide beam followed by near miss code in a wider beam just an instant before the gun fires.
6. If the gun was aimed correctly, the RPH will receive a kill code, if not it will receive a near miss code. Having received the weapon's transmission the RPH's transmitter would delay re-transmission so as to simulate shell flight time.
7. The RPH down-looking transmitter would fire the appropriate codes onto target area in appropriate beam widths to simulate kill and near miss zones.
8. The RPH might finally then drop noise makers and smoke to alert other troops in the vicinity that the target is taking indirect fire.

CONCLUSION

The Remotely Piloted Helicopter system called WIDEYE would be a simple and inexpensive solution to the problem of simulating indirect weapon fire. Because of its mobility and endurance it could be used in several engagement simulations in different areas of the exercises only moments apart. In addition it could be employed in area effects weapon simulation. Also, since several guns would have the same target only one RPH would be needed per target. Hence, only a very few RPH's would be needed even in the largest exercises. Since part of its payload is a TV system, it could also be used to help evaluate and supervise the exercise.

ACKNOWLEDGEMENT

The authors are indebted to Mr. D. Howell, Mr. P. Goddard, Mr. G. Hodge, and Mr. G. Austin of Westland Helicopters Limited of Yeovil, Somerset, U.K., for supplying technical information on the WIDEYE system.

REFERENCES

[1] Indirect/Area Fire Weapons Effect Simulator Study, International Laser System Inc. Special Program Division Catalog, Orlando, Florida.

[2] Indirect/Area Fire Weapons Effect Simulator Study, (Contract No. N61339-76C-0070), International Laser Systems Inc. Orlando, Florida.

[3] MILES System Description, Technical Library, Naval Training Equipment Cente (NTEC), Orlando, Florida.

[4] REALTRAIN, System Description TC 71-5, Technical Library, Naval Training Equip ment Center, Orlando, Florida.

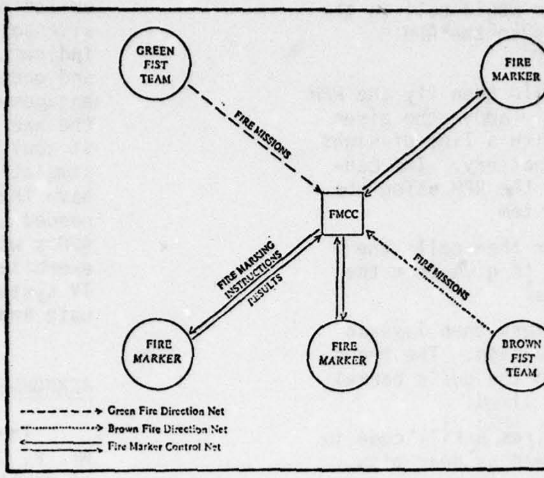


Figure 1. MILES indirect fire radio nets [3]

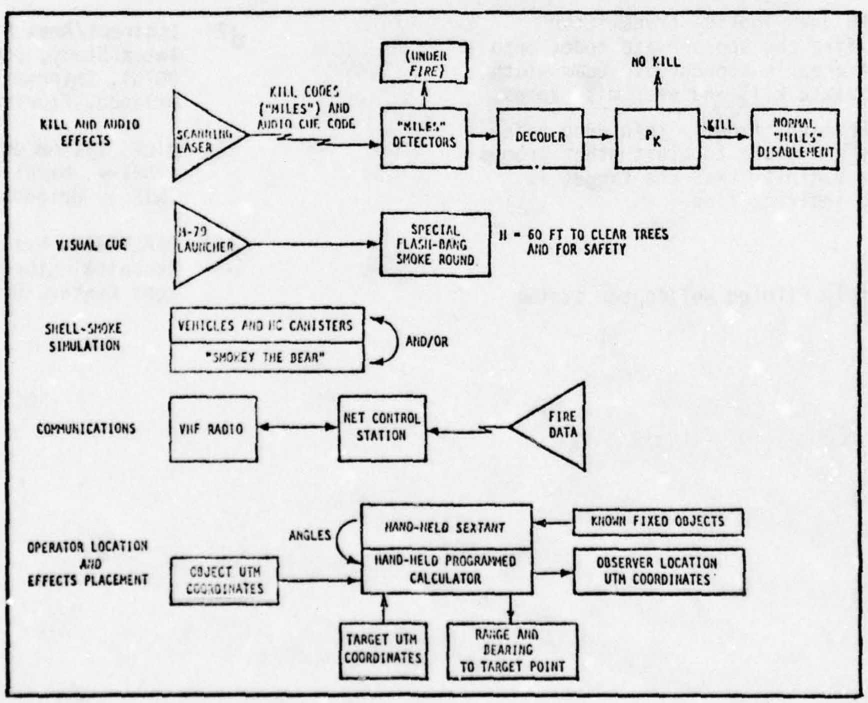


Figure 2. Schematic of recommended elements of optimal system [1]

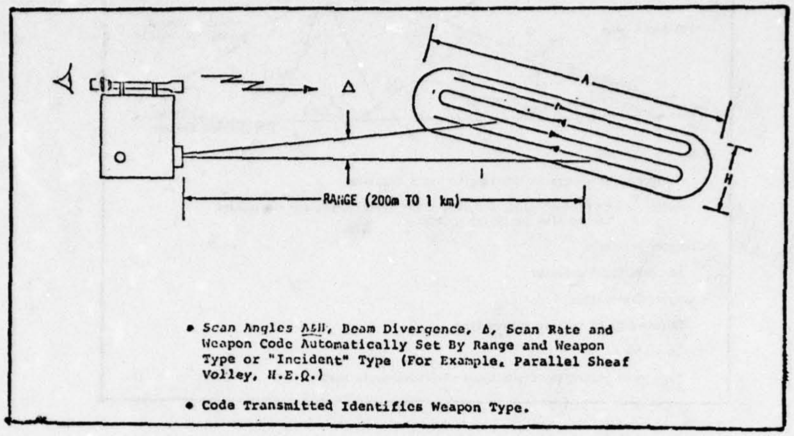


Figure 3. Scanning laser [1]

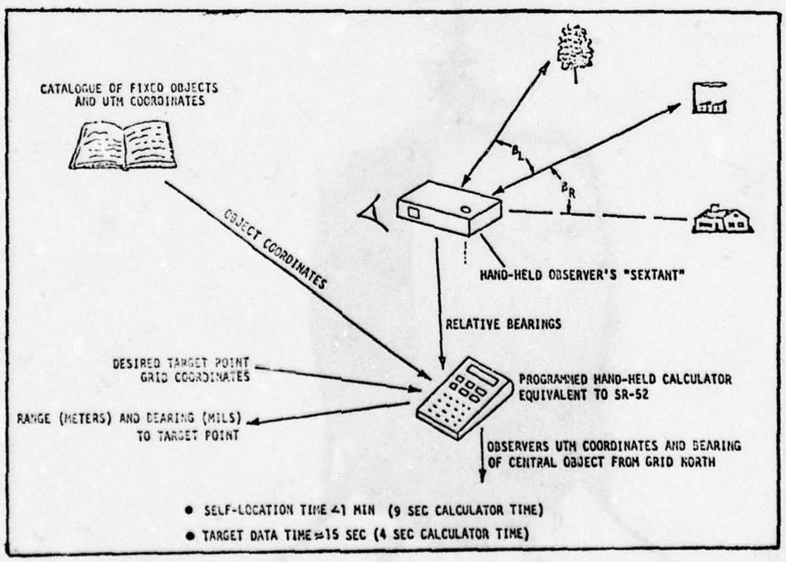
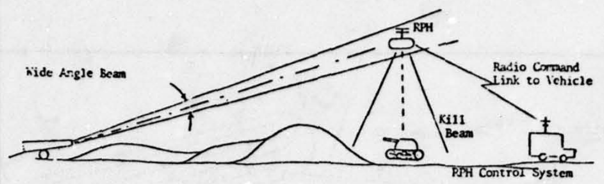


Figure 4. Position-finding and target area location via relative bearings [1]



Helicopter Control

Navigation-TV camera in RPH to give exact location.

Radio Link-TV picture using CCD, low light level camera for controller and to fire laser transmitter.

Helicopter Detectors

Standard MILES detector

Helicopter Transmitter

Standard MILES vehicle transmitter

Artillery Laser

High power pulsed injection laser with wide-angle beam

Figure 5. Suggested indirect fire simulation-schematic diagram

Figure 6. Westland Remotely Piloted Helicopter called WIDEYE

Figure 7. WIDEYE being prepared for launch. The system is easily transported by two men.

Figure 8. WIDEYE control console. TV display will allow controller to see intended target in addition to providing transceiver for laser relay in indirect weapon fire simulation.

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A VERSATILE WEAPON ENGAGEMENT SCORING SYSTEM
(LWESS)

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INTRODUCTION

The Lightweight Weapons Engagement Scoring System (LWESS) was conceived by the TRADOC Combined Arms Test Activity (TCATA) and was designed and built by International Laser Systems, Inc. (ILS). LWESS is an evolutionary replacement of TCATA's aging Weapons Engagement Scoring System (WESS). The goals set for LWESS were the result of the lessons learned from the use of WESS. LWESS has not stood the test of time in the field, but it is evident that a giant step has been taken in achieving these goals.

Specifically, TCATA required realtime casualty assessment (RTCA) by the target without support from an omnipotent central computer. It was also required that test data be collected by each player and saved for communication back to central as conditions allowed. TCATA needed an improved installation, maintenance, test control, and test coordination concept to minimize the recurring cost of test support. And, last but not least, the engagement simulations' algorithms, cues, and signatures needed improvement.

RTCA by the target without support from central is achieved by LWESS through the use of a distributed processing concept. Each LWESS field unit is an independent processor. They are interconnected by laser communications and connected to central by a telemetry link. An LWESS target may be attacked either by another LWESS unit (via the laser) or by the central computer (via the telemetry). In either case, the attack message itself provides the necessary and sufficient information for the target to consummate the engagement. The results of the RTCA are communicated back to central on a prioritized basis as the telemetry allows.

The LWESS data collection programs are modular and generate time-tagged data to be placed into the appropriate prioritized first-in-first-out (FIFO) memory buffer as the events occur. The LWESS communications program extracts the oldest message from the highest priority FIFO buffer on each transmission. The telemetry is error-checked and the last message is repeated until it is successfully communicated to the receiver.

More than any other evolutionary aspect of LWESS, the installation, maintenance, test control, and test coordination concepts require the test of field-use to judge. However, these concepts still appear to be a step in the right direction.

A typical LWESS installation consists of only four units in a vehicular installation and three units in a man-pack installation. All interconnecting cables are identical, except for their length. The cables are thin and flexible because of the system's serial data bus architecture. The installers do not need a lot of different cables and boxes. The maintenance support is also simplified because each LWESS can be used in any weapon-target application. LWESS uses built-in test programs monitored by central to assist in the assessment of field operability. LWESS has a large communications vocabulary to support initialization, system validation, data collection, and communications protocol.

The LWESS system includes a hand-held Keyboard Input/Output Device (KID) to facilitate test control and coordination. The KID has many uses such as inputting forward observer data for artillery strikes into the free play battle, or communicating to maintenance personnel during installation and maintenance periods.

Perhaps the most important attribute of LWESS is its field units' program. An inherent attribute of computer programs is the low cost of moving a new concept from the laboratory into the field hardware. One simply loads memory with the new program. This is an awesome capability. Even the most basic characteristics of LWESS can be changed. LWESS, for example, currently communicates through an external telementry system (the Basic Portable Device) to a central computer (the Automatic Data Collection System) both of which represent 1970 technology at TCATA. An integrated communication system is planned for LWESS which will increase the data transfer rate from 8 bits per second to over 200 K bits per second. This change will require the modification of the communications program module of the LWESS but will not impact its existing hardware. The system was conceived to allow and facilitate modular growth of hardware and software as concepts and capabilities change.

The LWESS program was designed in a structured, modular manner to facilitate growth. It is also highly parameterized. Essential attributes such as the correlation of the tonal cues to specific weapon classes are centralized in a few memory locations. If a test requires these tones to be changed, or new combinations to be added, it is a simple pre-test specification. This specification of parameters is

accomplished through an intelligent, interactive, prompting terminal at the depot support level. The assemblage and characterization of all players for a test iteration are defined through this terminal. The test control officer identifies each player's weapon, its characteristics, and a player's vulnerability to each different weapon. Commonly used weapon and target characteristics are stored on floppy discs and may be recalled by mnemonics such as "M60A2 MG" for a tank's maingun.

The cues and signatures chosen for LWESS are very basic. They are not intended to emulate the event, but rather to provide the player with an identifiable cue. The cueing and signature generators are under program control. The LWESS concept for generating unique cues and signatures is to vary combinations of a small set of cue and signature generators. Thus, the maingun may have a firing signature of five simultaneously-fired smoke cartridges and a short burst of strobe light flashes while a missile may be represented by five sequentially-fired smoke cartridges and a long sequence of strobe flashes. The philosophy of LWESS allows unique signatures without unique boxes and their attendant logistics problems.

TESTING VERSUS TRAINING

The testing community has historically emphasized the collection of objective data from simulated engagements while slighting the need for battle realism. The emphasis has been on the accuracy of the data collected and the ability to collect different kinds of data for different tests. Specific tests often require the design of custom data collection hardware. Meanwhile, the training community has sought to achieve realistic battle simulation and has slighted the usefulness of data collection. The training community has viewed instrumentation as a weapon surrogate. It must allow natural weapon employment (no negative learning) both from the gunner's and the target's prespective.

Experience is modifying the views of both. The testing communities' experience with data collection is demonstrating the obvious: the objectivity of the data collected is directly related to the authenticity of the battle simulation. The silent maingun and the unscathed casualty equally effect the players motivation and the quality of his participation. If it doesn't go "boom", it can't be much of a weapon. If the target doesn't "explode", it can't be hurt. The results of a test may be a major input to an important decision. The data analyzer would prefer to make judgements or take data collected from a real battle. The degree of compromise acceptable to the test community is basically a question of economics and technology. The testing community is moving toward the training requirements for a realistic battlefield simulation to achieve their goal of collecting objective data.

The training community is also gaining experience with instrumentation in tactical field training exercises. Realtime casualty assessment and authentic battlefield cues and signatures are well established requirements in field training exercises today. The training value of test exercises such as the Attack Helicopter Instrumented Test and the Division Restructuring Test, conducted by TCATA at Ft. Hood, are well documented. However, the need for determining "who shot who" is now becoming evident. It is not enough to run the troops through a field exercise so that they can learn from their own experience in a pseudo war. Good learning requires replaying the battle for peer and instructor critiques. This is where self learning is reinforced and transferred to the group. This can only be done if the battle's salient and descriptive data are recorded. The historical split between testing and training needs and requirements are becoming a matter of emphasis. Both communities value realism, non-negative learning, data collection, simple installation, low-recurring operating costs, high reliability, and post-trial replays. This closeness of needs and requirements suggests a sharing of systems and resources to minimize development costs and to maximize the benefits of scale.

The Lightweight Weapons Engagement Scoring System (LWESS) is an instrumentation system designed for the testing community to simulate a wide variety of weapon-target systems in a free-play, two-sided, simulated battle for use in combined arms testing. The LWESS is also designed to facilitate the collection of objective data. LWESS' high reliability, light weight, small size, low power, low cost, logistic simplicity, and its essential flexibility will allow it to serve many applications in both the testing and training communities. This paper will discuss some general characteristics of LWESS, but will focus on its flexibility, for it is this flexibility which makes LWESS unique in the world today.

LWESS DESCRIPTION

The Lightweight Weapons Engagement Scoring System (LWESS) consists of several units. These include field instrumentation units, field support units and the depot support unit. The major objective of the LWESS was to accommodate the wide variety of future weapon/target systems and the scenarios under which future tests would be conducted. This objective dictated that the software associated with the UFE microprocessor must be parameterized, modular and top-down structured. This software approach has many advantages including:

- Modules that are independently written and debugged;
- Modules that are easily documented;
- Modules that may be easily modified without affecting others; and
- Modules that may be added or deleted as required.

Various software modules perform all the basic algorithms used in LWESS including the weapon simulation, the target vulnerability, the attrition, the peripheral communication, and the central facility communication algorithms. These basic modules are made more flexible by using parameters for characterizing the various weapon and target combinations which are to be simulated.

The parameters which characterize the various weapon and target combinations can be programmed into the LWESS by the Software Development System (SDS). Basically these parameters fall into three categories; weapon characteristics, target characteristics, and weapon/target system characteristics.

The weapon parameter definition tables will contain the following:

Weapon Name
Example - M60A2AP (Tank Gun with armor-piercing round)

Weapon Class Number
A number 0 to 9 which defines the generic class of the weapon.
0 - No Threat
1 - Direct Fire, semi-automatic
2 - Direct Fire, Automatic
3 - Direct Fire with different possible round type
4 - Target Tracking Missile
5 - Guided Missile
6 - Target Designator
7 - Designator Guided Missile
8 - Mine field
9 - Indirect (artillery)

LEM Number
Number of LEM's generated per LER for each weapon simulated.

Reload Delay Time
Minimum time between firings for weapons other than automatic.

Ammunition Decrement
Number of rounds subtracted from the ammunition supply for each LER transmitted.

Round-to Round Delay
Time between successive LER's for an automatic fire weapon.

ETI Table
Estimated Time of Impact Table - time of impact of each range-dependent attacking weapon as a function of the engagement range.

Some subtle points about the above parameters should be given. For example, suppose an automatic weapon has a firing rate of 25 rounds per second but the maximum LER rate is 10 per second. This can be simulated by letting each LER be equivalent to three rounds and setting the Round-to-Round delay to be .12 seconds. The result is 3 simulated rounds each .12 seconds or 25 simulated rounds per second firing rate. The target vulnerability characteristic will also need to account for the weapon characteristic. The P_K used an LER will be the P_K for three real rounds.

The target characteristics are tables of target vulnerability. These consist of tables of kill probability as function of range for each of 31 different weapons. Formulating these P_K tables requires a knowledge of both the weapon and target.

Once the weapon parameter and target parameter tables are made, they are stored on floppy disks. After a few training exercises there will exist a library of weapon and target characteristics which can be used to define a particular weapon/target system. The weapon/target configuration definition will include the following parameters:

Weapon Complement
Assignment of weapons to each mode/weapon select switch position. The assignment may be zero to 4. If zero weapons are assigned, the system is a target only.

Trigger Assignment
Which trigger is associated with the various mode/weapon switch positions.

Ammo Bank Assignment
Which ammunition supply is associated with which mode/weapon switch position.

Ammunition Allocation
Defines the ammunition supply for 1/4, 1/2, and full for each of 4 ammunition banks.

Equipment Definition
Define which pieces of LWESS equipment will be used for the particular weapon/target system.

Minimum Range
This is the minimum range at which two players on the same team can kill each other.

Team Number
Designates players into two teams.

Some examples will clarify the above definitions. If the weapon was an M-16, then the switch would have single-shot capability on position 1 and automatic on position 2. The same trigger would be assigned to position 1 and 2 and there would be only one ammunition supply bank required for both switch positions. Now, if the weapon was a maintank gun with three different types of rounds, there would be one trigger for all three switch positions but there would be three different ammunition supply banks. There will be other systems which may have multiple weapons which would use a common weapon site, so that one laser could be used for all the weapons but the system would have different triggers and ammunition supply banks for each weapon. Other systems may require up to four different lasers and triggers to simulate four weapons on a common vehicle. The point to be made is that the LWESS has the flexibility to handle a variety of different weapon/target systems.

The minimum range programmable parameter is due to TCATA testing experience. In the field, players will see a potential target at a range which is difficult to determine if it is a friend or foe. If the rule is that friendly cannot kill friendly, then the player fires at the target without identifying whether the target is friend or foe. If the rule is that friendly can kill friendly, then there is a likely case of accidental kills resulting from firing in close formation due to reflection from nearby objects. This minimum range solves both of these problems.

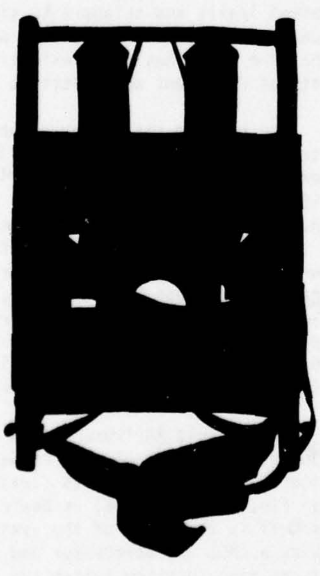
LWESS field instrumentation units are designed to support an undefinable set of weapon/target configurations because of its flexibility. The Universal Field Element (UFE) is basic to all configurations. It is the heart of the system. The UFE contains a CMOS microprocessor and space allocated for a position location system and a communication system. The UFE contains the program which characterizes the LWESS. This program is loaded into UFE by the Shop Service Module (SSM), a field support unit. The depot support unit (the Software Development System) facilitates test iteration design, program parameter changes, and program development. The output of this support unit is a set of UFE programs loaded into the SSM to support the field test.

The UFE is designed for battery powered manpack operation for 24 hours, as well as vehicular installation. The UFE with its battery pack for manpack or portable operations -- or with its power supply for vehicular operation -- weighs less than 17 lbs. and measures 12 x 13 x 4.9 in. Figure 1 shows the LWESS personnel configuration and Figure 2 shows the LWESS vehicular configuration.

The Miniature Laser Weapon Simulator (MLWS) is only "miniature" when compared to earlier generations. However, the MLWS is small enough to mount effectively on an M16 rifle. It weighs 1.2 lbs. and measures 3 1/4 x 7 x 2 in. The MLWS is a single beam GaAs laser with selectable divergences of 3, 5, and 10 milliradians. It has a trigger sense input, a laser output detector, and a fire mode-control switch. The functionality of both the trigger and switch are under computer control and may change from test to test. Typically, the trigger input will sense electrical continuity to initiate weapon firing and the switch will select mode of fire (i.e., automatic or semi-automatic). The laser output detector is a part of LWESS' built-in test equipment.

MINIATURE LIGHTWEIGHT
WEAPONS SYSTEM
(MLWS)

PERSONNEL DETECTOR AND PERSONNEL
CUEING SYSTEM
(PDPCS)



MANPACK

UNIVERSAL FIELD ELEMENT
(UFE)

Figure 1. LWESS PERSONNEL CONFIGURATION

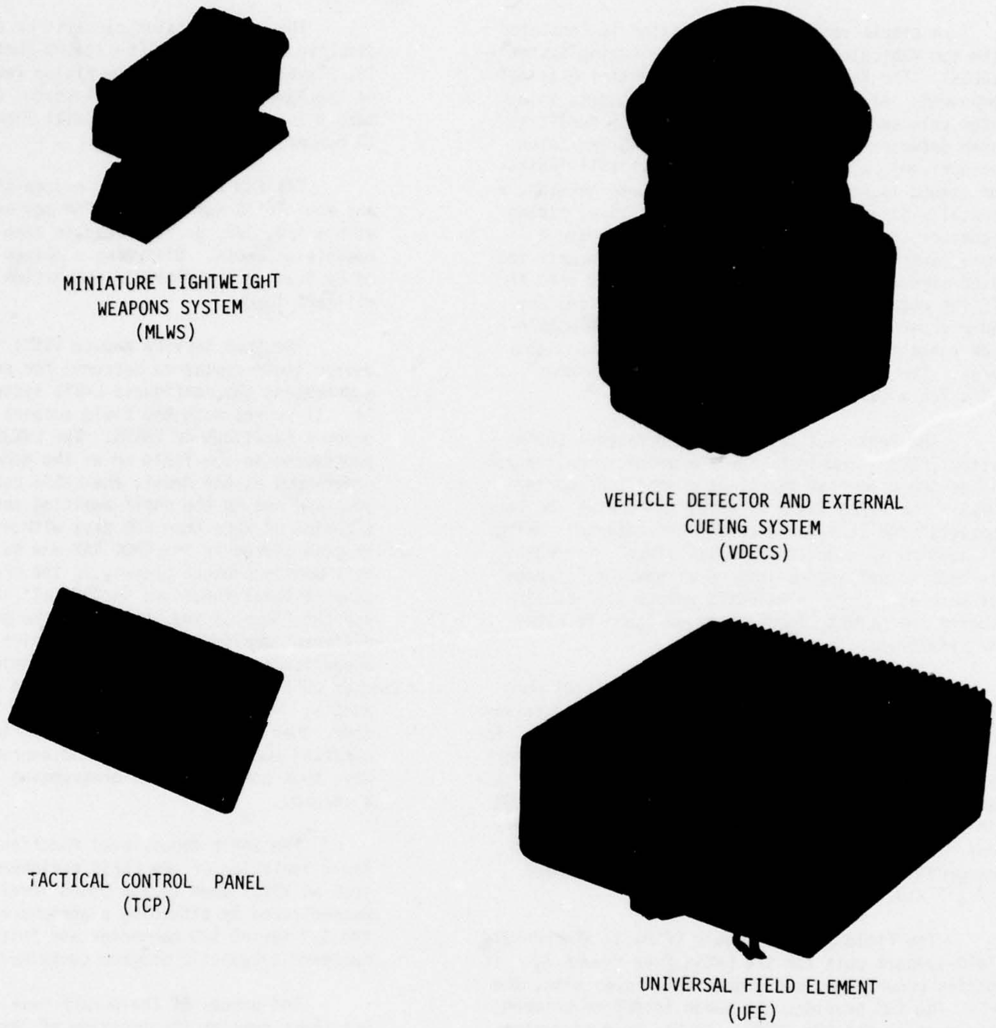


Figure 2. LWESS VEHICLE CONFIGURATION

The Tactical Control Panel (TCP) is the system's control and information display element for vehicular installations. The TCP facilitates the LWESS's support of up to four gunner-selectable weapon systems by allowing as many as four MLWS units to be attached to the TCP and selected by a control input switch. This switch may also be used to select one of four ammunition banks for use in a single weapon (such as a maingun). The switch provides an operator's input into the system which is interpreted by the program. The interpretation of this switch is parameterized so that it may be readily changed from test to test. The multiple weapon and selectable munitions capability of LWESS is a unique and powerful attribute. It provides a cost-effective answer to the playing of sophisticated weapon platforms of the future.

The TCP has seven indicator lamps whose significance is controlled by the program. These will typically be used to cue salient engagement data internal to the vehicle, such as the weapon ready to fire or weapon/target system killed. In addition to these seven visual cues, the TCP also has an audio output connected to the vehicle's intercom system and audible cueing system. Several distinctive sounds can be generated to aurally cue various battle conditions such as incoming artillery. The TCP also has 4 banks of numeric displays under program control which are (for example) useful in displaying the remaining quantity of ammunition of up to four types of shells in a tank system. The TCP weighs 2.4 lbs. and measures 4 x 7.3 x 4.5 in.

A simple vehicular installation is completed with the Vehicular Detector/External Cueing System (VDECS). The VDECS compacts all essential external components into one unit. The VDECS houses, in a totem pole arrangement, a hemispherically sensitive laser detector (actually good to 10 degrees below the horizon), a hemispherically active kill indicator strobe light, a kill indicator smoke grenade, a frontally directed, hemispherically active, firing signature strobe light, and 64 firing signature smoke cartridges. The VDECS' detector converts the laser signal to a logic pulse and feeds it into the UFE for decoding. Each of the cueing devices are under program control and may be varied to obtain a wide range of unique weapon/target cues and signatures. The VDECS weighs 14.6 lbs. and measures 7.3 x 7.5 x 14.5 inches.

The Personnel Detector and Personnel Cueing System (PDPCS) combines, for the manpack application, all of the essential functions of the TCP and the VDECS. The PDPCS has a detector to receive the laser "bullets" and it has "internal" and external cueing, all mounted in a modified helmet liner. The PDPCS has both visual and audible cues; however, it does not have any smoke. The PDPCS weighs 3.3 lbs., including the helmet liner, and is designed to allow the infantryman to have free play.

The Keyboard Input/Output Device (KID) completes the picture that is the field instrumentation portion of LWESS. The KID has full alpha-numeric input and output capability with a few special characters. The KID has an eight character vacuum fluorescent display for low power consumption and daylight visibility. The KID provides a source of ancillary test data and a means of communicating with field personnel. The KID weighs 2.3 lbs. and measures 4.7 x 7 x 3.3 inches.

The Field Service Module (FSM) is a hand-held field-support unit for the LWESS (see Figure 3). It obtains power from, and signal interfaces with, the UFE. The FSM provides the human interface between the operator and the LWESS. It has an 8 character alpha-numeric display, seven status lights, a keyboard, a display brightness control and an ammunition supply arm/disarm switch. The FSM has the ability to turn the LWESS power on and off. The alpha-numeric display and the seven status lights are used to display information to the operator from the LWESS. The status lights indicate what type of information is being displayed on the alpha-numeric display. The keyboard is a four-by-four matrix of keys which provides full alpha-numeric data entry by the operator to the LWESS by employing four levels of coding.

The FSM performs the system checkout test after the LWESS has been installed and programmed. The checkout uses the program contained in the LWESS along with parameters of the particular LWESS. For example, a personnel system would not have a vehicle detector system, but would have a personnel detector, and if this LWESS was not configured this way, then it would not pass the checkout test. Each LWESS component specified by the programmed system configuration parameter is tested and the result of the test is displayed on the FSM.

The player status can also be examined and displayed by the FSM. The status includes Player ID, Player Weapon Type, Ammunition remaining in each of the Ammunition Banks, Kill status (Killer ID, Weapon Type, Kill Range, and Kill Time) and Vehicle ID number.

The FSM can define or change the player's ID and vehicle ID number. The FSM may arm the player with a 1/4, 1/2, or full load in each of the four ammunition banks. Disarming a player is accomplished by loading the player's ammunition banks with an all-zero load.

The Shop Service Module (SSM) is a portable device (self-contained battery) for program loading and testing the configured LWESS system (see Figure 3). It serves both the field support and depot support functions in LWESS. The LWESS UFE can be programmed in the field or at the depot level. If programmed at the depot, the LWESS could be powered down and set on the shelf awaiting installation for a period of more than 500 days without losing the program stored in the CMOS RAM due to the single "D" cell memory protect battery in the UFE. The field support level functions include all those described for the FSM plus the loading of the programs for 31 different weapon/target systems which may be used in a particular exercise. The programming for a particular LWESS installation in the field was made very simple. The operator has to put the SSM in "program" mode, then enter the system name defined by the test director such as "AH-1Q-A1" and depress the "enter" key, thus completing the programming in a fraction of a second.

The SSM's depot level functions include the fault isolation of any LWESS peripheral component such as VDECS down to the board level. This is accomplished by attaching a peripheral component on the SSM Serial I/O connector and initiating the respective diagnostic program contained in the SSM.

The pieces of the puzzle have been described, but there remains the question of "Now, do they fit together?" In Figure 4 an engagement scenario is highlighted. Player A is attacking Player B. Player A pulls the trigger and "fires" his laser bullet. This "bullet" contains the necessary and sufficient data to allow Player B to accomplish RTCA without support from the omnipotent "Central Facility." The MLWS used to fire the LWESS bullet conforms to TCATA's engagement simulation philosophy. That is; the probability of kill is a factor of the probability of hit and the specific vulnerability of the target to the incoming munition. TCATA has sought to minimize the effects of aiming and alignment and folding into the target's equations and the weapon/gunner's probability of hit. Thus, the LWESS probability of kill is the probability of kill given that the gunner spotted the target and pulled his trigger.

Data generated from this engagement is communicated to the central facility to facilitate test control and post-test playback and analysis. It is important to note that the RTCA is not supported by the data communications; rather, it is the RTCA which generates data for communications.

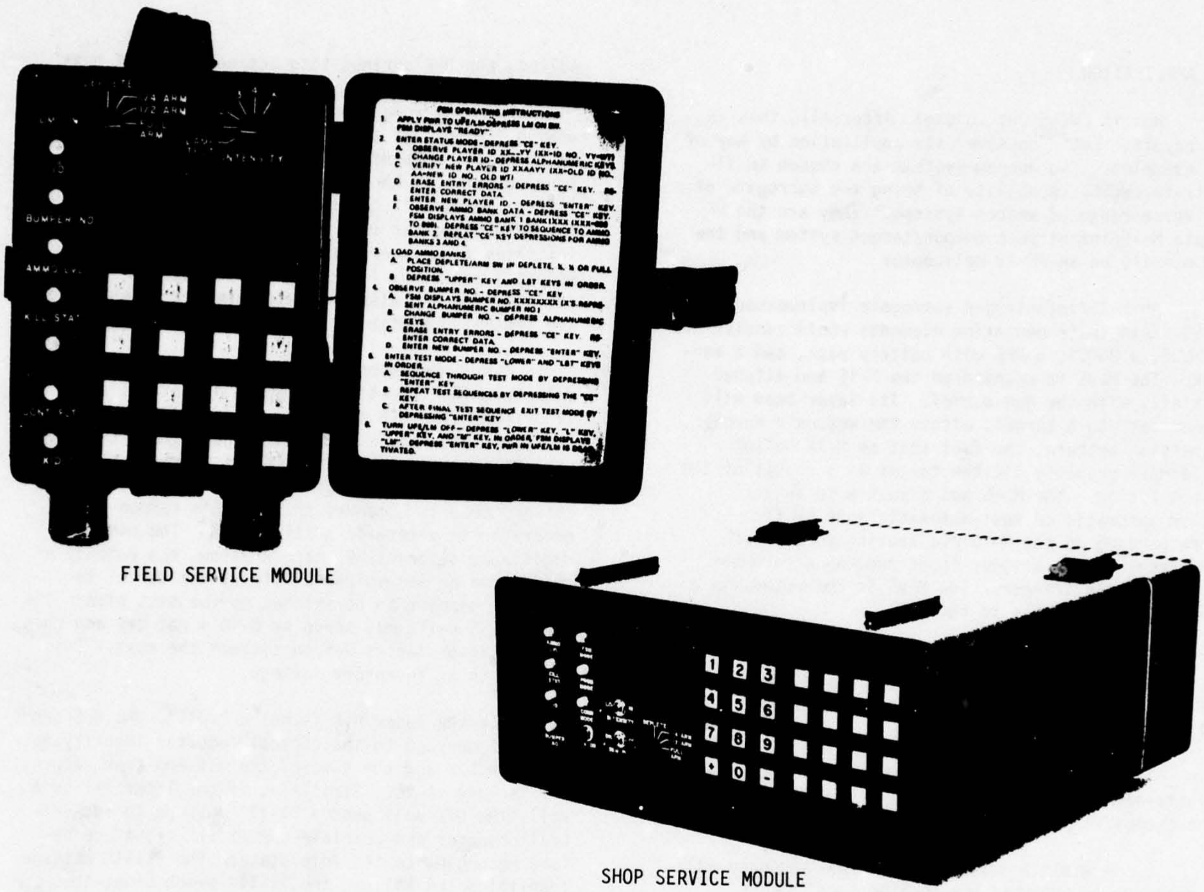


Figure 3. LWESS FIELD SUPPORT EQUIPMENT

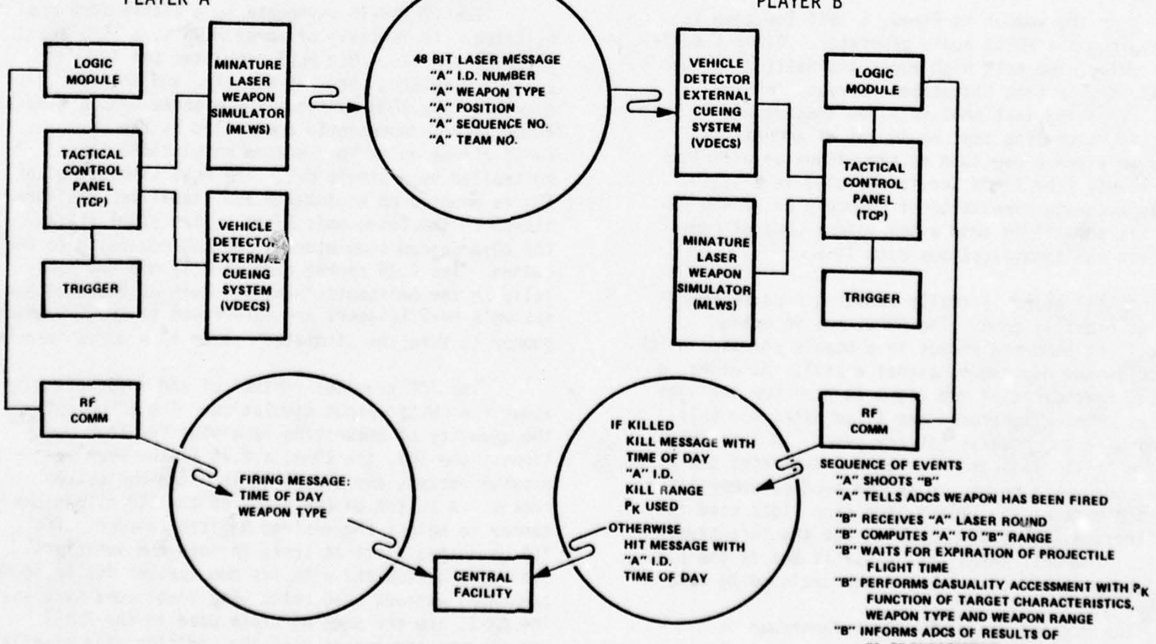


Figure 4. LWESS ENGAGEMENT SCENARIO

M16 APPLICATION

How is LWESS put to use? After all, this is the payoff. Let's consider its application by way of two examples. Two weapon systems are chosen to illustrate LWESS' capability of being the surrogate of a diverse range of weapon systems. They are the simple M-16/infantryman weapon/target system and the TOW missile on an AH-1S helicopter.

An M-16/infantryman surrogate implemented with LWESS field instrumentation elements would consist of an MLWS, a PDPCS, a UFE with battery pack, and a manpack. The MLWS is mounted on the M-16 and aligned coaxially with the gun barrel. Its laser beam will communicate to a target, within the weapon's normal dispersion pattern, the fact that an M-16 bullet would have probably hit the target as a result of the weapon firing. The MLWS has a switch to select either automatic or semi-automatic mode of fire corresponding to the M-16's operating modes. The MLWS receives its trigger input from an attachment to the weapons trigger. The MLWS is connected via a flexible coiled cable to the UFE.

The PDPCS replaces the infantryman's helmet. This "helmet" is very busy during an engagement. The cueing capability of the PDPCS is programmed as follows:

1. An artillery barrage is signaled to the infantryman by a sequence of five one-half second tone sweeps.

2. A missile screaming past the squadron will be noted by a repeated low-to-high tonal sweep.

3. All other non-lethal laser hits which need cueing are cued by an amber light under the helmet's beak. This provides a general "underfire" cue.

When the weapon is fired, a soft low tone is emitted from the PDPCS audio generator. After a half-second delay, two soft high tones are emitted to cue the infantryman that his weapon is ready to fire again. When the last shot is fired these tones do not occur, signaling that he is out of ammunition. He may be given a new load of ammunition by a field support unit (the Field Service Module) in a logistically accurate simulation of resupply or he may receive his ammunition from a benevolent central computer via the communications data link.

A kill event is really exciting because everything goes off at once. The PDPCS has an orange strobe light atop the helmet in a beanie position which is used in the daytime to signal a kill. At night, a subdued, rear directed red light is used for the same purpose. These signatures are illuminated for only five minutes to conserve battery power. A latchable positive "kill" indicator is set and indicates the kill without consuming power. A second subdued amber light under the beak of the helmet (the same light used for underfire cueing) is turned on to cue the infantryman himself. The only think that was left out is the playing of "taps", and that was a tough decision to make.

The UFE is carried by the infantryman in a "campers backpack" and serves as the system's brains. It is the local control center. When the trigger is pulled, the UFE springs into action. The UFE asks questions such as "Is the target system alive?", and "Are there any remaining rounds?", before it initiates weapon firing. If these are answered "yes", then it looks at the mode of fire switch on the MLWS to determine which of the four possible weapon characteristics tables will be used for this firing. Using the M-16 automatic mode table, for instance, the UFE initiates five laser messages, each containing the weapon's position, its type, and its unique identification. The UFE also initiates the transmission to the central computer of a time-tagged firing message.

When the laser pulses impinge on the target's detector, the target's UFE begins its attrition algorithm. The UFE takes the decoded laser message and calculates the engagement range. The UFE then uses this range and the attacker's weapon type to select a specific probability of kill (P_K) code. This P_K code is compared to the UFE's random number generator to determine a kill event. The use of a digitized, alterable P_K matrix allows the potency of the weapon or the vulnerability of the target to specific weapons to be matched to the test plan. The same LWESS units may serve as M-16's one day and then as opposition forces weapon systems the next. This results in an inventory savings.

If the laser hit is not a "kill", the UFE sends a "miss" message to the central computer identifying the attacker and the time of the hit and then returns to its idle state. Similarly, if the laser hit is a kill, the UFE will send a "kill" message to the central computer and initiate the "kill" signature before returning to its idle state. The "kill" message identifies the killer, the "kill" event time, the engagement range as calculated by the target, and the probability of kill used in the engagement processing.

AH-1S APPLICATION

The TOW/AH-1S surrogate is a little more complicated. It consists of three MLWS's, a TCP, two VDECS' and a UFE. One MLWS simulates the TOW, another simulates the 2.75 rockets, and the last simulates the 20mm cannon. These three weapon simulators are independently controlled by the UFE. LWESS allows up to four weapon simulations to be controlled by a single UFE. The MLWS simulating the TOW is mounted on a gimbaled and stabilized platform slaved to the Telescopic Sight Unit's (TSU) optics. The 20mm cannon simulator is mounted coaxially to the cannon. The 2.75 rocket simulator is mounted coaxially to the helicopter's axis. Each of these weapon system's real triggers are interfaced to the TCP and the gunner to fire the simulated weapon in a normal manner.

The TCP provides control of and information about the LWESS weapon simulation. The TCP displays the quantity of ammunition remaining for four munitions: the TOW, the 20mm, a 2.75 17 lb. high explosive rocket, and a 2.75 10 lb. high-explosive rocket. A switch on the front of the TCP allows the gunner to select the desired munition/weapon. The TCP generates distinct tones through the vehicle's own audio system and with its own speaker for those personnel without head sets. The tonal cues used in the AH-1S are the same as those used in the M-16/infantryman simulation with the addition of a missile firing cue and a warning tone to signal the targets' designation by opposing forces.

The two VDECS are mounted on the AH-1S wing tips to provide full spherical sensitivity to attack. The firing signature is programmed uniquely for each weapon. The 20mm cannon is simulated with both strobe lamps flashing twice for each second of real time firing. Both 2.75 rockets are simulated by the simultaneous firing of four smoke cartridges and the flashing of the strobes for five seconds. The TOW is simulated by firing six smoke cartridges time sequenced in pairs over a 10 second period and flashing the strobes at a slow rate for 10 seconds.

The UFE is mounted inside the AH-1S and controls all of the action. There is too much activity to address in a reasonably sized paper, thus the discussion here is limited to the TOW engagement with a little attention given to the 2.75 rocket or 20mm cannon. A TOW firing is communicated to the intended target by a laser message. The laser's beam width is 10 milliradians. The laser message is repeated--except for the timing data--20 times a second and contains the TOW's identity, type code, firing location, and elapsed time in seconds since the firing event. The timing data is incremented each second of elapsed flight time. The target sends one missile attack message to the central computer when the first laser message is received. The target has three requirements which must be met to accomplish a TOW hit:

1. The target must be lased before the elapsed time number in the attacker's laser message is incremented above the vulnerability threshold parameter (0-31 seconds). This threshold may be set low by the test control officer to simulate a missile system which must track the target during the early stages of its flight. Conversely, the threshold may be set high to simulate a missile which could be brought into the target from outside of the MLWS's divergent angle. Statistics on individual player performance can be collected by LWESS for post-test analysis and critique.

2. At least one laser message must be received during each n seconds where n is a parameter (0-25.5 seconds) set by the test control officer to reflect a target tracking accuracy requirement made on the attacker. Statistics on tracking accuracy can be kept for each attacker on a player-by-player basis.

3. Finally, the LWESS missile hit algorithm requires one of the last n messages to hit the target where n is a parameter (1-256). This parameter reflects the aiming accuracy required as the missile's flight nears its end. It may be set high or low as the missile's characteristics dictate.

If the incoming TOW has not met all of the target requirements, a missile fly-by message is sent to the central computer identifying the attacker and time of the initial "hit". However, if it does meet the requirements, then the UFE executes its attrition algorithm. In the attrition algorithm, the engagement range is determined, the correct P_k is selected and processed, a "kill" or "no-kill" result is determined and the appropriate response is made. The central computer may reward evasive action by sending the target an "abort" message, thus terminating the missiles' effect on the target.

The weapon will continue firing the TOW laser until the central computer sends it an expected time of impact message and the time of impact occurs. Or, failing to receive such a message, the weapon times itself out or the gunner aborts his own missile. Having expended one TOW, the weapon system is ready to fire again.

When a 2.75 rocket is fired, the laser message is repeated 15 times in one second. Those 15 messages are the 2.75 rocket. The target determines range and uses the appropriate impact delay time before entering the attrition algorithm. However, the hit message is transmitted to the central computer as soon as the laser hit occurs. The central computer may award evasive maneuvers by sending the target an "abort" message.

SUMMARY

LWESS was designed by International Laser Systems, Inc. for TCATA to serve as a universal weapon/target surrogate, to generate engagement descriptive data, and to collect and forward test data. The LWESS, as implemented today, is supported by TCATA's Automatic Data Collection System and the Position Reporting and Recording System. Its modular design concept allows an orderly growth to newer technologies. The communications algorithm is fault tolerant and will support a passive test where all data is stored locally (up to 800 time-tagged engagement events) for post-test recovery. This buffer is also useful in saving data which would otherwise be lost in extended communications outages that can occur when a tank backs its antenna into a tree. The free-play RTCA continues even during these outages.

Several common weapon algorithms have been designed into the LWESS. They are: direct fire, gunner-guided missile, designator (third party) guided missile, fire-and-forget missile, and indirect fire (attack via the communications link).

Weapon simulation includes signatures and cues. LWESS is unique in its approach to signatures and cues. LWESS provides the user with the basic building blocks: swept tones, audible pops, light flashes, and smoke. The test designer can specify a unique signature for each of the 31 possible weapons. The recognition potential of the signature is controllable by using the building blocks in varying quantities and sequences. The simulation costs are thus reduced while maintaining their effectiveness.

A major advantage of a distributed system such as LWESS is that players can be added without a major impact to the central facility. LWESS will support up to 31 weapon types and each weapon may be used by 256 players. The total LWESS field deployment is therefore limited to 7,936 players and 31 different weapon types. The laser fire power of each weapon simulator is as strong as eye-safety constraints will allow. The information required by the target will punch through most battlefield environments. The target then uses range and P_k to determine the RTCA.

LWESS will be an effective weapon/target surrogate that facilitates the monitoring, recording, analysis, and evaluation of data from TCATA tests for several years to come. The attributes possessed by LWESS also seem to meet the needs of the training community.

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MARKSMANSHIP AND GUNNERY LASER DEVICE (MAGLAD)

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INTRODUCTION

The Marksmanship and Gunnery Laser Device (MAGLAD) system (Figure 1) provides simmulation of the firing of live M16A1 ammunition during marksmanship training. An eye-safe laser transmitter produces pulses of harmless light in place of potentially lethal and expensive live ammunition. The system includes simulation of firing against both stationary and moving full-scale targets, in addition to a 1/12th-scale record fire range.

The system provides the following benefits:

a. Economy.
   (1) Allows the optimal use of limited range facilities by eliminating or reducing projectile safety requirements.
   (2) Reduces high-dollar support costs through elimination of range safety personnel
   (3) Cuts costs by reducing the requirements for live ammunition and extends the barrel life of weapons because live ammunition is not required.
   (4) The MAGLAD is attached to the trainee's weapon. Thus, special rifles are not required.

b. Expanded Training Capability.
   (1) By reducing the requirement for live ammunition, the training capability is greatly increased. Time that would have been expended in the replacement of targets can be utilized for simulated firing.
   (2) Firing ranges can be set up in areas where live ammunition firing is prohibited, thereby greatly increasing the training capability.

c. Versatility.
   (1) The system versatility is such that simulated firing may be conducted indoors as well as outdoors. Also, the laser rifle may be fired using blank ammunition or with a trigger switch which simulates the trigger squeeze of a loaded M16A1 rifle.
   (2) The 1/12-scale record range can be easily dismantled and set up for operation at any designated site that is a minimum of 32 feet long and 35 feet wide (such as an armory).

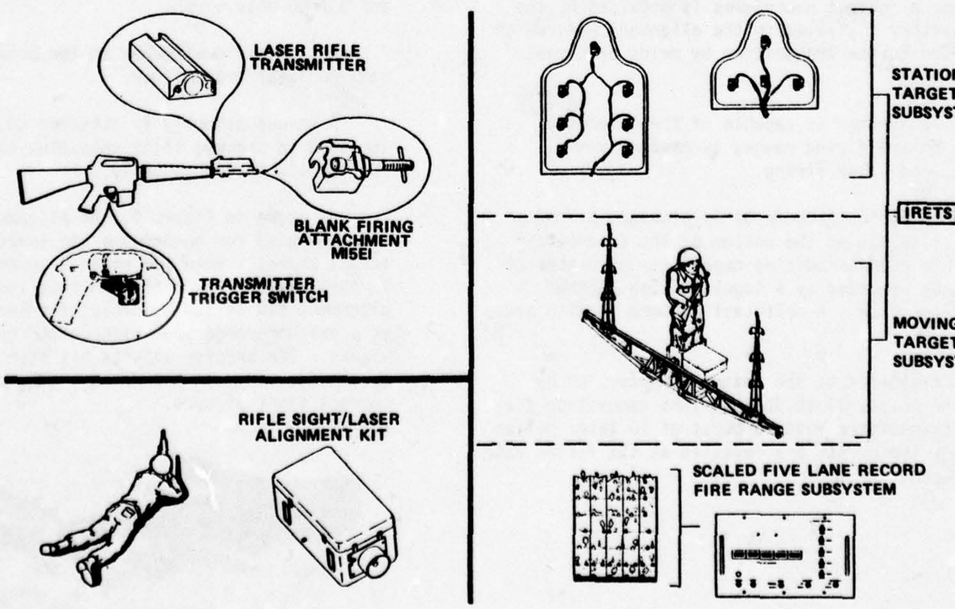

FIGURE 1 - MARKSMANSHIP AND GUNNERY LASER DEVICE (MAGLAD) LASER RIFLE MARKSMANSHIP TRAINER DEVICE P4252

SYSTEM DESCRIPTION

Laser Transmitter.

The laser rifle transmitter (Figure 2) is utilized for simulated range firing at stationary or moving targets equipped with laser radiation detectors, and operated as part of the Infantry Remoted Target System (IRETS), or for simulated firing at the 1/12-scale targets on the scaled record fire range.

The laser transmitter consists of a lightweight, Gallium Arsenide (GaAs) laser diode transmitter configured for attachment to the barrel of the M16A1 rifle, and a trigger switch adaptor which is connected to the transmitter by means of a cable assembly. When in use, the trigger switch adaptor is positioned directly behind the rifle trigger so that when the rifle trigger is pulled the laser transmitter is fired.

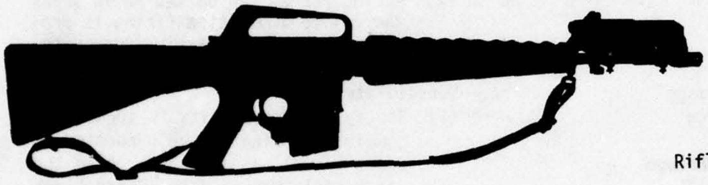

FIGURE 2, MAGLAD TRANSMITTER MOUNTED ON M16A1 RIFLE

Power required to operate the transmitter on the firing range is provided by a 9-volt battery housed in a compartment within the transmitter case. Power required for operation of the transmitter during rifle sight/laser alignment procedures is provided by the 12-volt battery installed in the alignment kit, which is connected to the transmitter by means of a cable assembly.

The transmitter is capable of three modes of operation on the firing range; automatic, semi-automatic, and blank firing.

Mode selection (Figure 3) is provided by means of a rotary switch on the bottom of the transmitter case, with a rounds-limiting capability of either 20 or 30 rounds provided by a toggle switch on the bottom of the case. A self-test feature is also provided.

When triggered by the trigger adaptor, or by sensing the muzzle flash during blank ammunition firing, the transmitter emits a burst of 16 laser pulses per round. The bursts are repeated at the firing rate of the weapon.

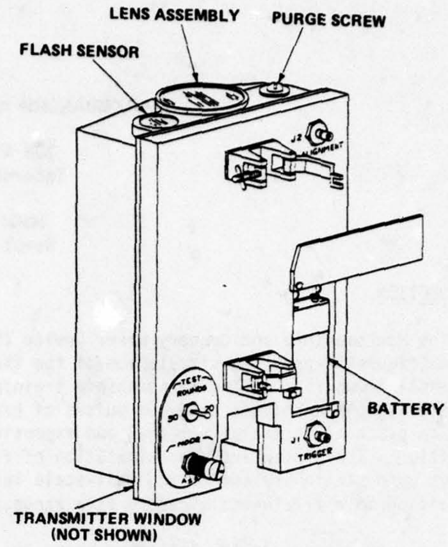

FIGURE 3. LASER RIFLE TRANSMITTER

Rifle Sight/Laser Alignment Kit.

A unique feature of the MAGLAD is the portable and self-contained alignment kit which provides for precise field alignment of the weapon sights to the laser beam axis within the click-stop resolution of the sights.

The alignment kit consists of a portable case equipped with carrying handles, input and output power connectors, a viewing window, ACTUATE switch, and a removable cover.

A sight tube attaches to the M16A1 rifle and installed laser transmitter.

A shroud assembly is attached to the outside of the case to provide light shielding and an entry port for the sight tube assembly.

As shown in Figure 4, the Alignment Kit eliminates the need for cumbersome and inaccurate remote target boards. When the rifle alignment sight tube is installed on the rifle and inserted into the alignment kit shroud assembly, the laser beam appears as a bright orange spot silhouetted by the rifle sights. The shooter adjusts his sight until the orange dot rests on the front sight, producing the correct sight picture.

FIGURE 4. MAGLAD ALIGNMENT KIT IN USE

Rifle Laser Radiation Detector, Stationary Target Kit.

The stationary detectors in the MAGLAD system attach to standard 'E' and 'F' silhouette targets as shown in Figure 5. In combination with the sharp beam skirt of the laser transmitter they accurately define the target shape over a wide range of atmospheric conditions.

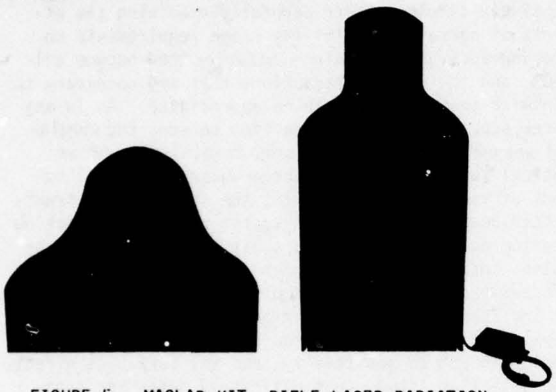

FIGURE 5. MAGLAD KIT, RIFLE LASER RADIATION DETECTOR, STATIONARY, MOUNTED ON "E" AND "F" TARGETS WITH RECEIVER-DECODER MODULE

The stationary target kit is utilized in conjunction with the Infantry Remoted Target System (IRETS). When the laser beam strikes any detector on the target, the resultant output of the receiver decoder is optically coupled to the IRETS control mechanism, causing the target to drop, and also recording a hit on the IRETS control console. E and F-Type targets are interspersed on a fixed range at distances of 25 to 300 meters to provide realistic marksmanship training.

The detector kit consists of seven laser radiation detectors installed on standard E-Type targets or four detectors installed on F-Type targets, two cable assemblies and a receiver-decoder assembly.

Each detector assembly contains a printed circuit (PC) board consisting of a silicon solar cell for detection of laser rifle transmitted energy, and electronic circuitry for preamplification of the detected energy to a useable level for an input to the receiver decoder.

The receiver-decoder assembly consists of a rectangular metal housing equipped with mounting flanges containing a PC board assembly. It receives and amplifies the summed output of all detector assemblies located on a single target and provides a seven millisecond output pulse to activate the IRETS target mechanism and counter circuitry when a hit is recorded.

Rifle Laser Radiation Detector, Moving Target.

The MAGLAD system also includes a moving target lead-angle mechanism system which requires that the marksman lead the moving target by the correct amount to achieve a hit. The amount of lead varies with the speed and range of the moving target. This MAGLAD moving target system is designed to interface directly with the Infantry Remote Target System (IRETS) moving target.

The moving target kit (Figure 6) consists of two detector arrays mounted on the MAGLAD boom assembly. The array provides aiming points (lead angles) for targets either approaching the shooter at a forty-five degree angle, or going away from the shooter at a forty-five degree angle. Normally the detector arrays will not be visible to the shooter who must determine the lead angle required to score a hit.

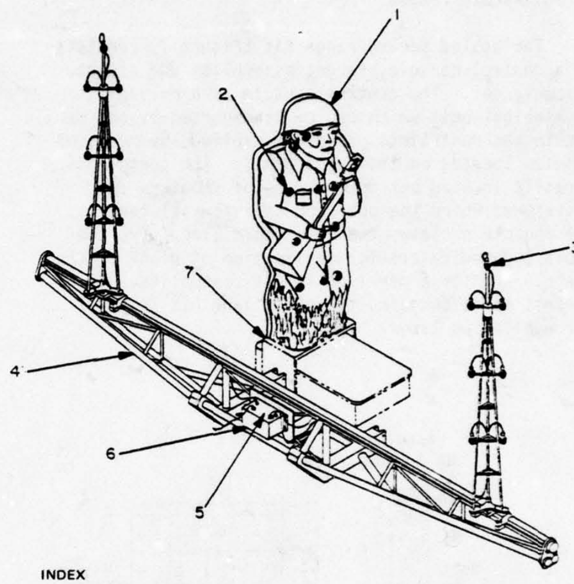

FIGURE 6. M^VING TARGET KIT

A modified IRETS three-dimensional (3D) target is provided with detectors to record hits when the target is stationary.

A control box mounted on the boom assembly contains three receiver-decoder PC boards to receive and decode the output of the detectors installed on the detector arrays and the 3D target. One additional control board selects the appropriate detector array depending on direction of motion.

Record Fire, Five Lane, Scaled, Kit.

For indoor training, MAGLAD provides a complete 5-lane Record Fire Range, scaled to 1/12 actual size. Each lane consists of 7 "E" and "F" type silhouette targets arranged in the standard record-fire configuration. The target firing distances are from 4 to 25 meters, corresponding to full-scale ranges of 50 to 300 meters. The targets are under control of a master console operated by the instructor. Each bank of targets may be erected or dropped independently, in any sequence and for any interval of time. A hit on any target is logged on the console display and, at the instructor's option, causes the target to drop. The standard MAGLAD transmitter is adapted to indoor, scaled firing by snapping a cap over the exit aperture, reducing the exit aperture and narrowing the beam size. This adaptation, together with the unique design concept employed

on the scaled silhouette targets, provides accurate target definition at all scaled ranges, and automatically compensates for parallax so that a weapon which is zeroed for full-scale range can be used indoors with no readjustment of the sights. The scaled Record Fire Range is intended primarily for use by Reserve and National Guard units which have infrequent access to full-scale ranges.

The scaled record range kit (Figure 7) consists of a control console, target assemblies and a cable assembly set. The control console is a portable, lightweight unit which can be transported by one man, within the restraints of system cabling, by means of handles located on the front panel. The console is normally located behind the line of shooters and positioned where the operator can view all targets. The console contains the electronic circuitry, controls and indicators for application of power to the console and for control of target assemblies. The control panel contains two-digit lane hit counters for monitoring target hits.

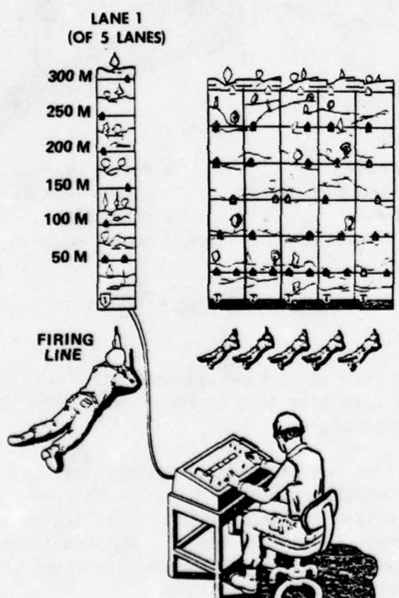

FIGURE 7. SCALED RECORD RANGE

The scaled range target assemblies consist of 20 F-Type scaled targets and 15 E-Type scaled targets. The assembly housing contains the target actuating mechanisms, a detector assembly and a detector amplifier. Each of the thirty-five target assemblies are functionally identical, but are physically different in that detector and target body configuration vary depending upon scale range bank placement.

Technical Considerations (System Design).

The principal requirement of the MAGLAD design, in fact the entire point of the MAGLAD system, is to provide a precise interaction between the laser beam and the target detectors which will accurately simulate the firing of service ammunition against the targets. Simulation accuracy must be maintained at ranges from 25 to 300 meters under all visibility conditions in which the trainee can take a sight picture on the 300-meter target.

The MAGLAD performance specifications appear deceptively simple. After carefully examining the effects of operating/visibility range requirements on scoring accuracy, certain subtleties then become evident, and the design precautions that are necessary to minimize these effects can be appreciated. As in any laser scoring system, interaction between the simulated weapon and the target is by transmission of an optical pulse or pulses. The angular or lateral extent of these pulses, that is, the shape of the transmitted beam, is a principal system parameter affecting scoring accuracy. To score a hit, however, the laser pulses must be detected by some means; the detection process requires that the amplitude of the laser pulse at the target exceed some threshold or sensitivity level. It is the interaction between beam shape, detector threshold sensitivity, and the variables affecting signal amplitude that ultimately determine scoring accuracy and simulation effectiveness. An additional complication affecting scoring accuracy is the cost imposed requirement of a finite number of detectors comprising the target array.

For a given transmitter power output, the amplitude of the laser pulses at the target is affected by at least four variables:

The instantaneous value of the atmospheric scintillation envelope;
The average value of atmospheric attenuation corresponding to prevailing visibility conditions;
The target range; and
The aiming error in relation to the shape of the transmitted beam and the target detector geometry.

In the MAGLAD it is only necessary to convey bi-level, that is, hit or miss information to the target, without regard to player identity or weapon hierarchy. Accordingly, the effects of atmospheric scintillation on scoring accuracy can be largely overcome by selecting a pulse transmission format which utilizes redundant pulses transmitted over a time interval exceeding the correlation interval of the scintillation envelope. The only concern here is that the pulse burst not be too long, or rifle motion during the burst could lead to erroneous scoring. Fortunately, studies indicate that an interval of 10 to 15 msec is adequate to ensure reception of the necessary number of pulses in the presence of severe scintillation, and that rifle motion during this interval -- even when firing blanks -- has negligible effect on the fidelity of simulation.

If the only factor contributing to signal level at the detector was the width of the transmitter beam, the effective simulation requirement could be met quite simply by specifying a "width" corresponding to the 0.4 mr, 1 σ dispersion error of the rifle, and assuming that the simulated dispersion error would remain constant over all ranges and all atmospheric conditions. However, the solution is not that simple. We customarily regard a laser beam width as constant, and to the extent that we refer to the off-axis angle at which the beam intensity is down by some specified amount relative to its boresight value, this usage is correct. The skirts of a practical transmitter beam are not infinitely steep,

however, but instead have a shape determined by laser source geometry and collimating optics design. In addition, the target detectors do not measure relative power, but produce an output whenever the signal level exceeds some preset absolute power threshold. As a consequence the angular width of the transmitter beam, as measured by the target detector, is not a constant, but depends upon beam skirt taper and signal level. Since signal level, in turn, depends upon both range and visibility, and since skirt shape is a parameter, that is at the designer's disposal, the considerations involved in configuring a system which will provide effective simulation over a variety of range and visibility conditions become more evident.

A further complexity is imposed by the desire to construct the target detector array using a minimum number of detectors. The absolute power threshold is developed from the sum of all detector outputs. As a result the effective beamwidth measured by a single detector is increased by the off-axis energy received by an adjacent detector in the array. The magnitude of the effective beamwidth increase is a function of the beam density distribution and off-axis displacement of adjacent detectors. As can be seen from Figure 8, the result of summing two detectors positioned a beamwidth apart forms a pattern approximating an ellipse. The dimensions of the ellipse are a function of the detector separation, individual detector sensitivity, receiver threshold and illuminating beam power distribution. The proximity of other detectors modifies the pattern in a predictable manner. Since the pattern modification results from summing off-axis energy arriving at adjacent detectors, care must be taken in the laser source and optics to assure repeatable characteristics in the beam power distribution. Similarly, the location of each detector relative to both the target edge and the other detectors is critical.

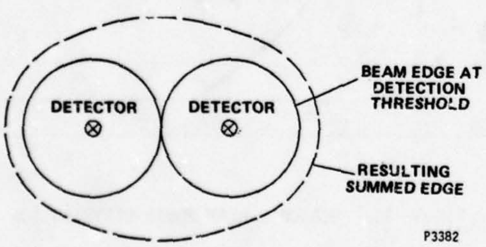

FIGURE 8. EFFECT OF SUMMING DETECTORS

Experience early in the program showed that extensive theoretical analyses could, at best, only approximate the effects that beam shape and detector location and sensitivity produce on simulation effectiveness and that, therefore, there was no analytic substitute for thorough field experimentation. Accordingly, extensive field testing has been used to verify and modify the system design.

FIELD TESTS

Laboratory and field tests were conducted to obtain data from which major design parameters could be derived. Source size and emission power can be traded for optical design parameters to generate a theoretically optimum beam shape. Size and cost constraints of the laser tended to drive the design towards shorter focal length optics. Early experiments with multiple junction diodes indicated "hot" spots within the beam which affected target definition and repeatability. These "hot" spots could be partially smoothed by use of a diffuser, but this approach softened the beam skirts producing large target size variations with simulated weather attenuation.

Figure 9 and Figure 10 are beam intensity profiles measured at 150 and 300 meters using a calibrated threshold detector. The source was a 6 mil dual junction diode with a total output power rating of 10 watts. The output power of the beam using a 9-inch focal length lens and an aperture of 1.125 inches was adjusted to measure 250 milliwatts. This was approximately 50% of the collectable power with this particular focal length and aperture, thus allowing for temperature dependent variations anticipated in the final configuration.

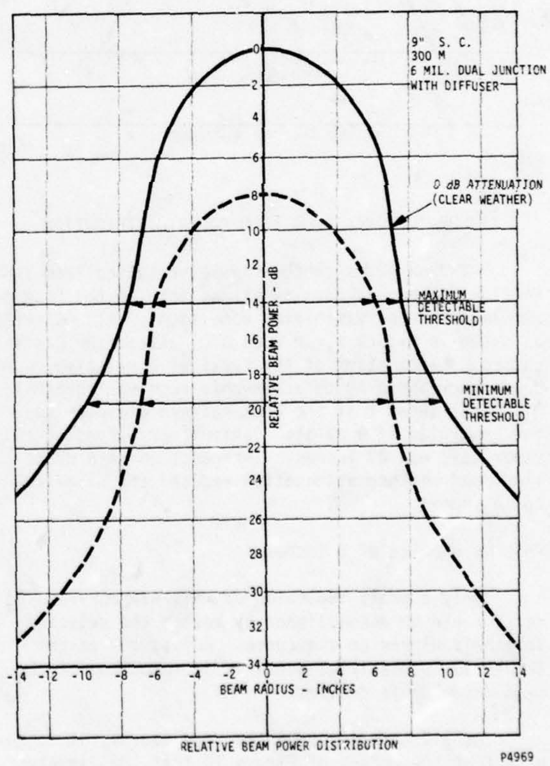

FIGURE 9. MEASURED BEAM POWER DISTRIBUTION

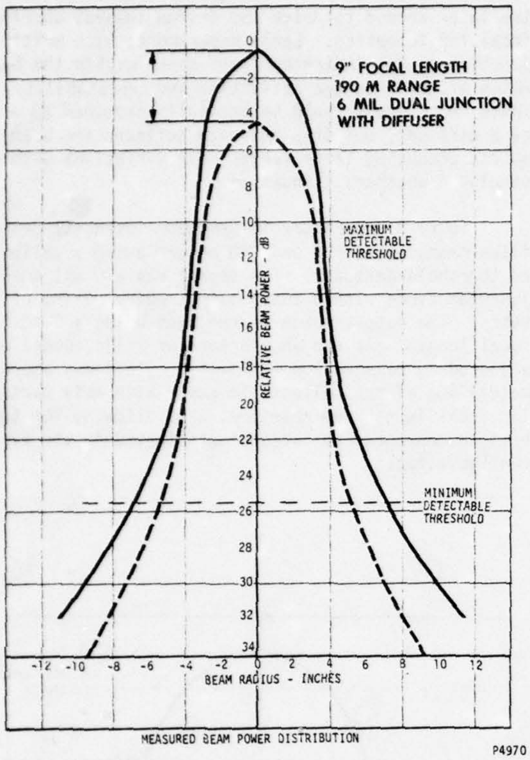

FIGURE 10. MEASURED BEAM POWER DISTRIBUTION

The dash lines on the figures resulted from insertion of neutral density attenuators in the beam to simulate reduced visibility conditions. At 300 meters, as shown in Figure 9, an 8 dB N.D. attenuator was inserted. Examination of the curve at a relative beam power corresponding to achievable receiver thresholds (19.5 dB) shows that the beam pattern diameter under the condition of 0 dB attenuation (corresponding to clear day) was 20 inches. Introduction of 8 dB of simulated weather attenuation reduced the diameter to 14 inches.

This is a delta of 6 inches.

Only a small reduction of this weather-induced delta could be accomplished by moving the detected threshold higher on the curve. Adjustment of the threshold is possible, however, if reduction of the mean diameter is desired.

At 150 meters, using the same source, it is apparent on the curves of Figure 10 that the diameter reduction caused by the insertion of 4 dB weather-induced attenuation is not beyond reason at this range. *Considerable improvement* in the delta can be made by raising the threshold to the 14 dB level, however. This also has the effect of reducing the mean beam pattern diameter from 12 inches to approximately 8 inches. Further raising of the threshold is possible if a reduction in the effective beam pattern diameter is desired when configurating a target array. The limit is reached when the threshold is raised to within 6 dB of beam extinction. This is considered to be an allowable safe power margin in a good design.

Referring again to the 300 meter case shown in Figure 9, a limit is reached at approximately 14 dB. This level allows 8 dB attenuation for weather and a 6 dB power margin. The effective mean beam diameter at this level is approximately 14 inches. It can be seen from these curves that at each range there is an optimum threshold to minimize the apparent diameter change as a function of weather attenuation. Furthermore, it is possible to adjust the effective beamwidth dimensions within limits when configuring a target edge.

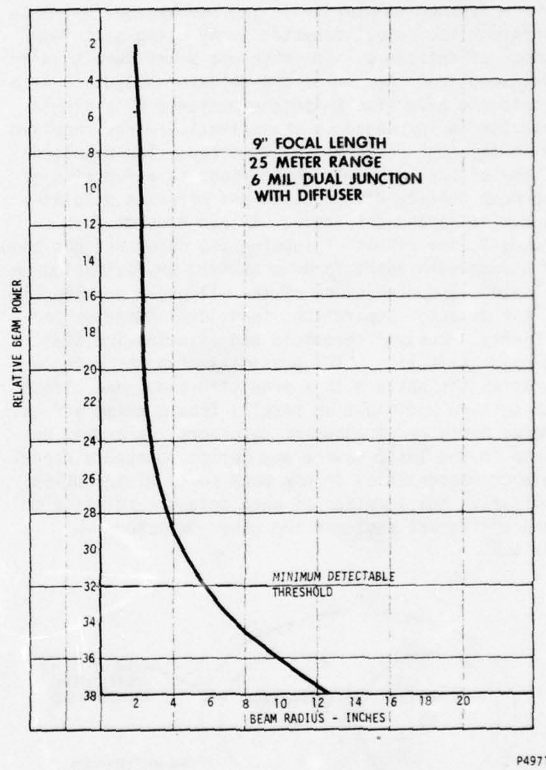

FIGURE 11. MEASURED BEAM POWER DISTRIBUTION

At ranges of 100 meters or less, the problem is reversed. Here the desire is to increase the effective beam dimensions beyond the divergence profile. It was expected that the diffuser would broaden the beam and, in effect, this is the case. Here, operation at or near the minimum detectable threshold is necessary to obtain diameters large enough to cover the target with a minimum detectable threshold when the beam diameter is 10 inches. Fortunately, at minimum range, minimum attenuation is incurred due to weather. Because of the slope of the curve a small change in the received signal level causes a large change in the effective diameter.

It could be concluded from the experiments described thus far that a beam approaching a theoretically *optimum* dimension of 12 inches could be generated at all ranges below 250 meters. At 250 and 300 meters, the body portion of the "E" target could be adequately covered with a single row of detectors.

The "head" of the "E" target, however, with a dimension of 8 inches, presented a major problem. The minimum diameter obtainable at 300 meters with an allowable power margin was 15 inches. Alternative solutions included the use of two detectors at the head which could be combined logically in such a way that a detectable threshold must be reached in both detectors to indicate a "hit". The body then would be covered by a single row of detectors. Since this would incur the use of two additional receiver amplifiers and threshold detector circuits with associated increase in cost, this approach was considered undesirable.

Instead, efforts were directed toward improving the beam density profile with a fiber optic collector attached integrally with the laser diode. Tests of these units indicated characteristics considered desirable. Namely, a more uniform source and a relatively sharp-edge profile.

The photograph shown in Figure 12 was taken of a beam imaged at infinity and viewed at 10 meters by an infared sensitive television camera. The uniformity of the brightness appeared to be a definite improvement over the diffuser smoothed image.

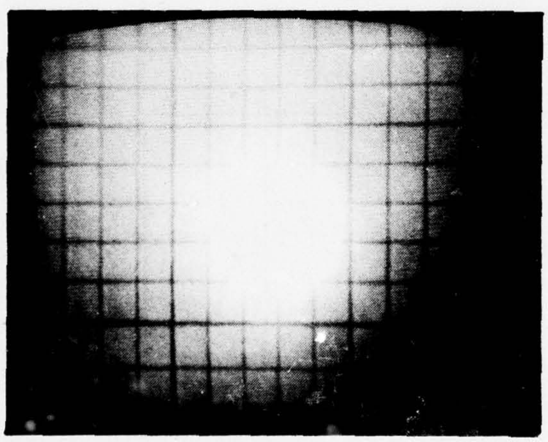

FIGURE 12. BEAM IMAGED AT INFINITY AND VIEWED AT 10 METERS

Beam profiles were generated using the fiber optic laser. Due to the sharpness of the beam profile a shorter focal length lens was necessary to obtain beam widths comparable to those experienced with a 9 inch focal length lens using a dual junction diode and diffuser. Figures 13, 14, 15 and 16 are profiles generated at 25, 100, 150 and 300 meters using a 136 mm achromatic lens. Dashed lines on the curves result from the insertion of weather induced attenuation. It can be seen that the reduced delta incurred by this attenuation is a function of the steepness of the skirts of the beam at usable threshold levels. At 300 meters the beam diameter can be adjusted to approximately 8 inches, providing a delta of 5 inches.

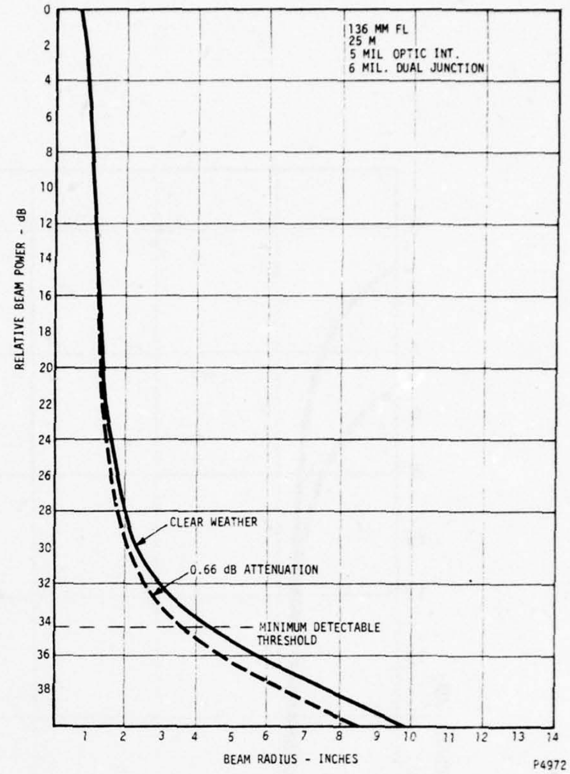

FIGURE 13. MEASURED BEAM POWER DISTRIBUTION

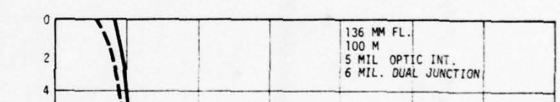

FIGURE 14. MEASURED BEAM POWER DISTRIBUTION

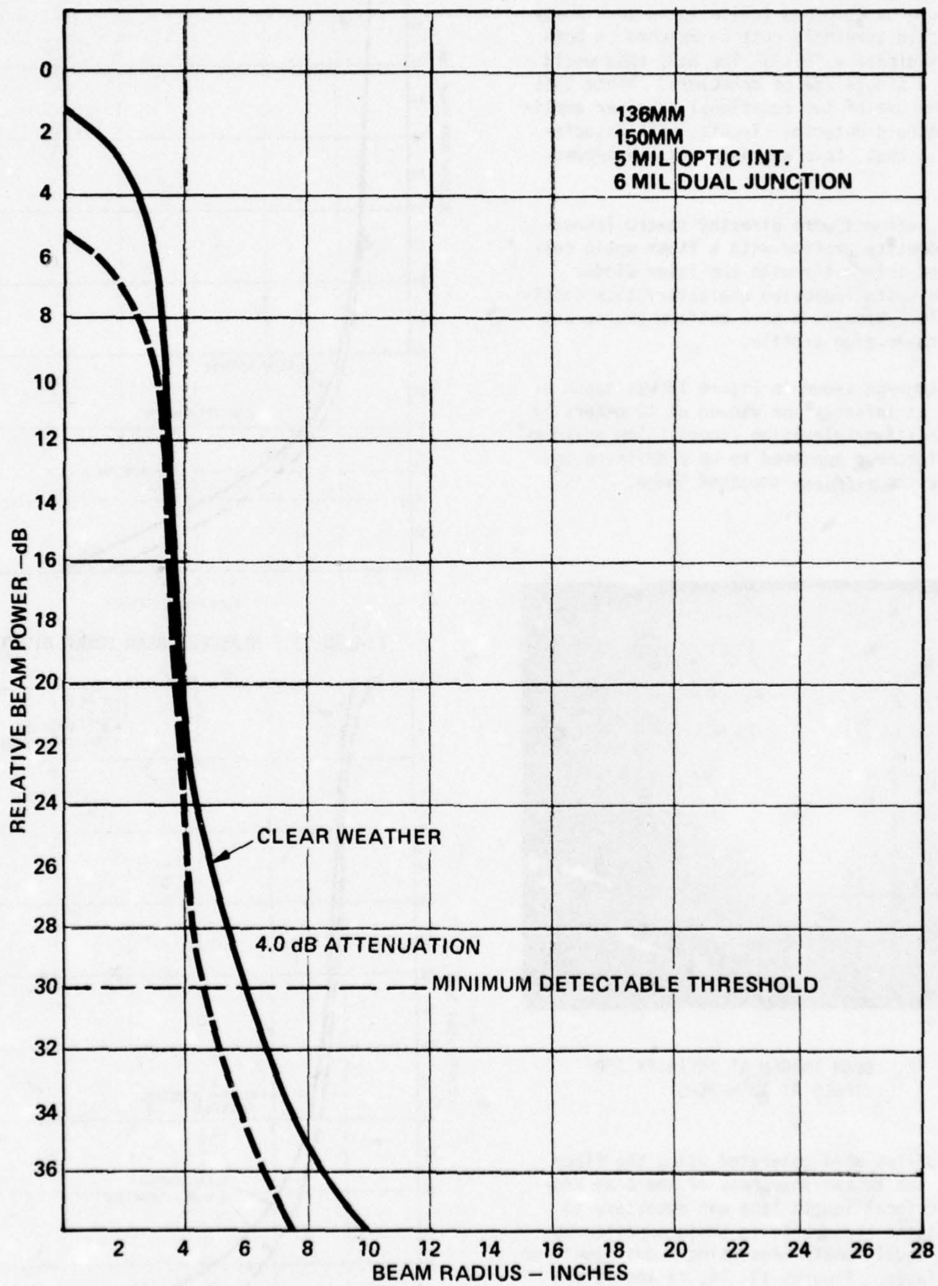

FIGURE 15. MEASURED BEAM POWER DISTRIBUTION

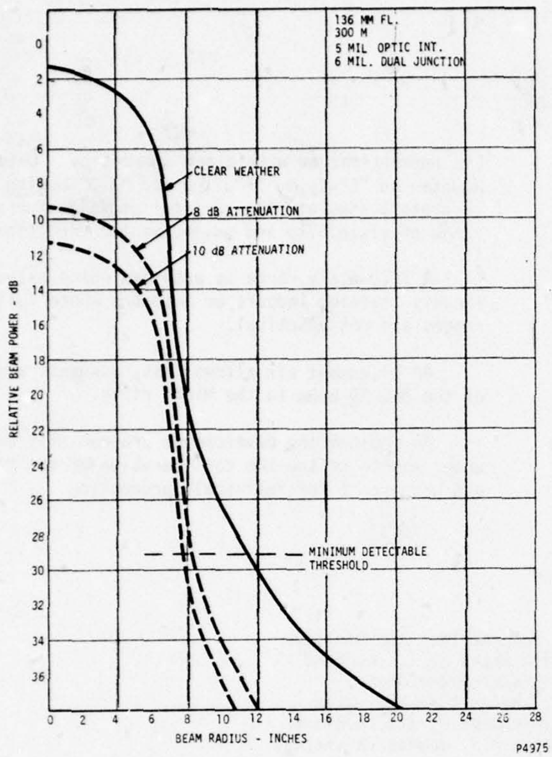

FIGURE 16. MEASURED BEAM POWER DISTRIBUTION

Five inches of change in apparent target edge was considered to be a good design goal at the 300 meter range since this is an error of roughly ± 0.2 mr which is one-half of the standard deviation of the weapon dispersion.

Examination of the beam profiles of 25, 100, 150 and 300 meters shows that a beam radius delta on an individual detector is minimum at each range when the detector threshold is at the maximum allowable threshold. This indicates that an increase in laser radiated power causes a decrease in the weather induced delta. Of more importance, however, is the corresponding decrease in beam profile diameter. A decrease in diameter is desirable at 300 meters to improve edge definition on the head. Reduction in diameter at the short range, however, though improving edge definition, tends to increase the required number of detectors to paint the short range "F" targets. The compromise selection of 5.35 inches for focal length optics is therefore justified.

Transmitter Design.

The primary design emphasis in the achievement of a sharply defined and homogeneous laser beam of very narrow dimensions that accurately defines the target for all ranges and conditions of operation has been accomplished. The resulting, optimized, MAGLAD beam has an angular divergence of 1-milliradian with extremely steep skirts produced by a fiber optic-homogenized laser source working into a corrected lens of 132 mm focal length. An internal temperature control maintains the laser output power substantially constant over the environmental temperature range.

Laser Radiation Detector Design.

The MAGLAD detectors employ inexpensive, reverse-biased, PN photodiodes (solar cells) to detect the transmitted laser energy. This type of detector may also be operated in an unbiased (photo-voltaic) mode. When operated in a reverse-bias mode and exposed to sunlight, a direct current flow is produced through the detectors which must be supplied by the system battery. When several detectors are involved, the current demand in strong sunlight far exceeds what can be supplied by a small battery for a period of time corresponding to a typical training exercise.

Some system designs recognize that it is difficult to meet the solar background current demand of reverse-bias operation and, instead, employ unbiased or photo-voltaic operation. This solves the battery problem but introduces an entirely different problem: the sensitivity of a solar cell in the unbiased mode varies greatly according to the amount of sunlight to which it is exposed, which means that the size and shape of targets instrumented with unbiased detectors will change with ambient light conditions.

This effect has been confirmed by laboratory and field tests conducted by ILS, and it is the reason that biased detectors are necessary, and are used, in the MAGLAD receiver. Thus, it is evident that the use of photo-voltaic detectors to instrument the MAGLAD targets would result in targets whose size and shape vary with weather, orientation to the sun, and time of day a clearly unacceptable basis for accurate, transferable marksmanship training.

The signal present at the solar cell output is at a very low level, so that many EMI sources could produce equivalent signal levels on the cabling between the solar cells and the amplifier. Amplitude discrimination would therefore be impossible. Time domain or digital filtering is not practical because the detector must respond to only a few pulses of a transmitted pattern which has already been randomized by atmospheric scintillation. With no reverse voltage bias applied to the solar cell detector, the detector would bias itself into saturation in the presence of strong background light even when the detector is preceded by an infared filter. A variety of solar cells were investigated, but none were found with the required sensitivity and which would not saturate when subjected to strong background illumination. Therefore, a solar cell detector/pre-amplifier package was placed at each sensor location on the target. This accomplished two objectives:

a. A supply voltage was made available to each solar cell so that sensitivity could be made independent of background light level by applying reverse bias to the cell; and

b. The gain present in the preamplifier allowed higher signal levels to be placed on the cabling between the detectors and the main amplifier so that noise pickup on this cabling is no longer of sufficient amplitude to cause a significant detection error rate.

STATUS:

Production of advanced design prototypes is complete and testing has been conducted at Fort Benning and Aberdeen Proving Ground. Although the final tests reports have not been completed, preliminary results appear to verify the design concept and the utility of MAGLAD for marksmanship training.

SUMMARY:

The MAGLAD system provides marksmanship training for the M16A1 rifle, using an eye-safe Gallium-Arsenide laser and silicon diode detectors. At the user's option, the system will function with a trigger switch (no ammunition) or with blank ammunition. Detectors mounted on "E"-Type, "F"-Type and "3-D" moving targets accurately simulate the targets' profiles for a wide range of visibility and environmental conditions.

A 1/12-scale range is provided which allows marksmanship training indoors or outdoors where full-scale ranges are not practical.

An alignment kit allows fast, accurate alignment of the MAGLAD beam to the M16A1 rifle.

An engineering development program will soon be under way to refine the configuration of the MAGLAD and prepare it for full-scale production.

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A COST-EFFECTIVENESS METHODOLOGY FOR AIRCREW TRAINING DEVICES

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A. Introduction and Summary

This paper provides a technical description of a methodology and associated computer software developed by Analytic Services for the Air Force Human Resources Laboratory (AFHRL) for evaluating the cost and effectiveness of devices used in aircrew training programs. The primary purpose of the methodology is to identify the most cost-effective mix of training devices (including aircraft, simulators, PTTs, etc.) for aircrew training for a given weapon system. The methodology is applicable to training programs at all levels for both existing and future weapon systems. The computer model requires input data on training requirements and device training capabilities, some of which is not presently routinely available. The model uses the requirements and capabilities data to identify all mixes of devices that can satisfy the training requirements; it then uses device acquisition and operating costs to select the most cost-effective mixes of devices for accomplishing the training and to compute the life-cycle costs of these sets of devices. The computer software is stored in AFHRL UNIVAC 1108 at Brooks AFB, Texas.

The model provides an automated procedure for the detailed testing of all possible combinations of devices for both existing and planned systems. It has options that provide flexibility by allowing the data to be input in several ways, and it is easy to perform sensitivity analyses by varying critical parameters. The flexibility makes the model useful to: budget personnel in justifying training device acquisition and tracking system costs after acquisition; design engineers in developing aircrew training device specifications; operations analysts in determining tradeoffs between cost and effectiveness; commanders in making procurement decisions for particular training programs; and higher-level decisionmakers in determining cost effectiveness trade-offs for training device procurement and in developing training device priority listings for new system acquisition or existing system modification. The model is designed to consider the overall impacts of different alternatives and, as such, does not incorporate detailed scheduling or allocation considerations. Alternatives that are identified as a result of this model should be explored in detail for their operational feasibility and to establish appropriate basing criteria.

B. Background

Use of flight simulation devices is becoming increasingly important for aircrew member training for major aircraft weapon systems. Acquisition of simulator trainers is now an integral part of all new weapon systems procurement programs. Planning for the development and acquisition of training simulation devices may begin as early as the weapon system requirement generation phase and is usually no later than the conceptual phase of advanced development. As with the weapon systems themselves, the cost of training simulators has increased substantially because of the general price and wage increases and the significant advances in simulator technology. These cost increases are expected to continue for future follow-on aircraft and their associated simulator trainers.

The development of the newer, sophisticated, and more realistic so-called full-mission capability simulators was motivated in part by anticipated savings in aircrew training. (Other reasons included conservation of petroleum products, improved safety, improved training for selected tasks, objective measurement of achievement, availability of aircraft for mission requirements, and a need to extend the life of operational aircraft.) The extent to which forecast cost savings have been realized is not known. The high cost of full-mission simulators has turned interest towards optimizing the utilization of relatively low-cost part-task trainers (PTTs), cockpit procedural trainers (CPTs), and instrument procedural trainers (IPTs). Just as the use of full-mission simulation can result in realized savings over employing aircraft for training, use of PTTs, CPTs, and IPTs rather than full-mission simulators can result in additional economies.

Establishing an optimal mix of the various devices for a training system has been difficult for the Air Force to achieve because of a lack of quantitative data that could be used to compare the effectiveness of the various types of simulator training with training in the aircraft and a lack of information on the life-cycle cost (LCC) of existing and planned simulation training devices. However, this situation is being addressed by current research programs on the training effectiveness and the transfer of simulator training to the aircraft and by new Air Force

Comptroller programs to collect and publish operating and support costs of existing simulator devices. In addition, methods for ascertaining acquisition costs of simulation devices for projected training systems are being developed at several locations throughout the Air Force.

C. Description of Methodology

Most training tasks can be performed using the aircraft, but at high cost. Additional training tasks, such as emergency procedures training, can only be performed in the devices because of safety considerations and unique device capabilities. The cost-effectiveness analytical process consists of balancing the capabilities of various training devices—including the aircraft, full-mission simulators, part-task trainers, cockpit procedure trainers, study media, classroom training, etc.—against the costs associated with their use. The best mix of devices will then consist of that set of devices (defined as an alternative) with the lowest cost that also has the capability to satisfy system training requirements. The analytic process is complicated by the fact that various training devices can be used for overlapping portions of the training requirement, with various levels of efficiency and at different costs.

The classic approaches to solving such an optimization problem are 1) maximize total system effectiveness for a given level of cost and 2) minimize the cost of reaching a prespecified or criterion level of system effectiveness. The two rationales are equivalent from a computational point of view; we chose the latter (minimize cost) because of the relative difficulty of calculating total system effectiveness as compared to calculating system costs, and because it allows the direct identification of solutions that meet the training requirements.

The cost-effectiveness of a training system, given a fixed set of training devices from which to choose, is influenced most directly by the number of each device procured. For this reason, we modeled this characteristic as a controlled variable. We modeled other variable system characteristics (e.g., utilization) as state variables, which depend on the controllable variable. We treat quantities that define system characteristics that do not vary (e.g., training device procurement costs, operation and maintenance factors) as fixed parameters. The most cost-effective mix of devices can be determined by testing all combinations of the integer values of the controllable variables.

Figure 1 is a flow chart of the cost-effectiveness model. The model is basically an interactive process that generates an alternative (a set of training devices), compares the capabilities of the alternative with system requirements, and determines the costs of alternatives that are effective. Effectiveness is defined as a binary attribute of the alternative (that is, whether or not the capabilities and availabilities of the training devices can satisfy system requirements). In this respect, it is a filter that discards from further processing those alternatives that do not have the ability to meet requirements. With the model,

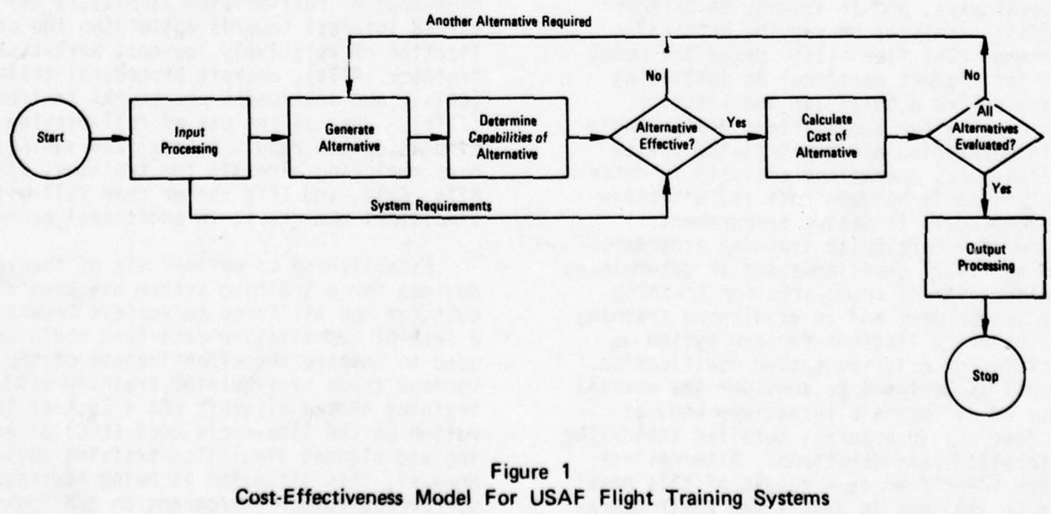

Figure 1
Cost-Effectiveness Model For USAF Flight Training Systems

we compute the life-cycle costs of all effective alternatives to identify the most cost-effective ones. The life-cycle costs of the most effective alternatives are available as output for use in further analysis and decisionmaking.

1. Input Processing

Inputs to the model include: training requirements data—number of training components (tasks), average number of hours required in each device for each trainee (aircrew member) to accomplish each training component, and number of aircrew members to be trained for each level of training; training device data—the ability of each device to satisfy each training component (a capability matrix), the maximum time each training device can be used for training purposes (in student-hours/week), and the number of training bases; and training cost data—procurement cost for each training device, operating and support (O&S) costs for each device, economic lifetime of each training device, and discount and inflation factors.

The major options available in using the model are in the selection of input data and include the following:

- Either functional or mission-related training tasks may be used as the basis for the analysis.
- The transferable requirements may be entered either as a function of the devices or as a function of the aircraft only.
- The capabilities may be expressed in terms of total requirements or in terms of transferable requirements only.
- The costs may be developed from basic cost-estimating relationships, or available cost experience may be used.
- TDY can be allowed or prohibited by appropriate selection of the controllable variables.
- Limitations on TDY can be expressed in terms of either training requirements for a specified sequence of training (e.g., number of trips per year) or an operational restriction (e.g., number of days of TDY per trip).
- Individual data items are separate inputs and can be varied independently for sensitivity analysis.
- Either escalated or nonescalated costs may be examined.

2. Generation of Alternatives

An alternative is a set of values for each of the controllable variables (i.e., the number of devices of each type). The model generates all possible alternatives by permuting each variable separately through its entire range of possible values. For example, for two device types each having between one and three devices, the alternatives are: 1,1; 1,2; 1,3; 2,1; 2,2; 2,3; 3,1; 3,2; 3,3.

The model examines all alternatives because: (1) the magnitudes of the number of controllable variables (types of training devices) and the ranges of each (maximum numbers) are relatively small (usually less than 10) so that the combinational enumeration is feasible, (2) the detailed data obtained will contribute to the discovery of rules for systematically identifying subsets of alternatives that are of particular interest, and (3) sensitivity analysis is facilitated by a complete enumeration of possibilities. The module in Figure 1 labeled "All Alternatives Evaluated?" ensures that all combinatorial possibilities are examined for the set of device types considered and for the range of possible numbers allowed for each device type.

3. Determination of Capabilities

The capability of an alternative is measured by its ability to satisfy training system requirements. The capability depends on the number of devices procured and the training abilities of each type of device.

There is an analytical difficulty in combining the training capability of individual devices to determine the overall training capability of a multidevice system. The problem arises because the capabilities of devices may overlap, making the specification of total system capability dependent on the specific combination of devices and the commonality between them. This sharply increases data requirements for the model.

We have attempted to simplify this problem, and reduce the amount of data required, by examining device capabilities for individual training tasks. The analysis distinguishes between capabilities that are specific to one device (for example, emergency procedures training in a simulator) and those that are not. For individual training tasks, we believe that device capabilities that are not unique to one device usually "nest"; that is, within a given transferable task, the most capable device can train everything the next lower capability device can train, and so forth. This assumption allows the use of data that specify the

maximum design performance of each individual device for each task (in hours of aircraft substitution time, and transfer of training ratio) without respect to other devices being evaluated. The assumption appears to be valid in most cases, and we expect its use at the level of individual training tasks will result in negligible error when aggregated over the whole training program. The assumption is not used for capabilities that are unique to one device.

The model can treat as training tasks either functional activities such as takeoff and landing, or mission-level activities—i.e., groups of sorties of a given type, such as transition, instruments, formation, intercept, basic fighter maneuvering, air combat maneuvering, air-to-air gunnery, etc. Our examination of a sample training program shows that data on training times are at present most readily available for mission-level sorties. Transfer-of-training ratios are, at present, not readily available or well-defined. Values for this study are estimates based on some relevant research and the qualitative experience of operations and research personnel.

4. Determination of Effectiveness

Determining the effectiveness of an alternative is accomplished by attempting to satisfy each training task requirement simultaneously, within the limits of the capability and total availability of each device. If all the training tasks can be accomplished, the alternative is effective and is retained for cost calculations; if not, it is discarded from further consideration in the model. In other words, since effectiveness is a system constraint that must be satisfied, the effectiveness of an alternative is binary (i.e., either it is effective or it is not).

The determination of effectiveness is accomplished according to the steps indicated in the schematic in Figure 2. For each task, the devices are ordered in terms of increasing capability (expressed in aircraft hours). Then, for each task, times are assigned to the devices to satisfy the total requirement* for all crews for that task. The times are assigned first to the least capable device up to its maximum capability, then to the next more capable device up to its maximum

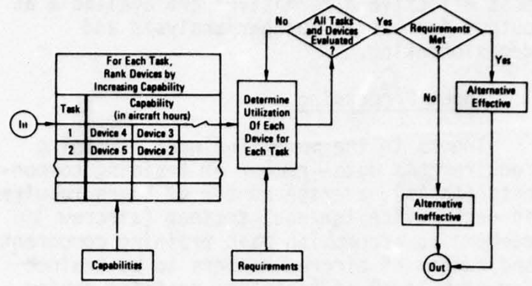

Figure 2
Details Of Effectiveness Determination

capability, and so forth until the requirement is met. This sequence is repeated for each task in all training syllabuses with the times accrued to each device summed and compared to the maximum availability of the device. An alternative mix of training devices is effective only if the capability exists to meet each requirement entirely and the hours needed for each device type do not exceed its total availability. Alternatives that do not meet these considerations are discarded; those that do are costed in the next module of the program.

5. Calculation of Cost

We chose to base the cost comparisons on the average annual cost for each of the effective alternatives. This is equivalent to using the total present value of each alternative. The advantage of using average annual cost is that the comparisons are made on an annual basis and are more reflective of budgetary expenditures. Also, the analyses are not linked directly to the period of comparison. The average annual cost of an alternative is related to the total present value as follows:

$$\text{Average Annual Cost} = \frac{\text{Total Present Value}}{\text{Sum of annual discount and/or inflation factors.}}$$

The life-cycle cost of an alternative is the present value of all acquisition, opera-

*Requirements for each task have two parts—weapon system (transferable) requirement, and a device (nontransferable) requirement. Transferable requirements can be met on a number of devices (the times required on different devices are related to each other by the transfer-of-training ratios) while nontransferable requirements must be met on the specified training device. In matching the capability to the requirement, nontransferable requirements (such as emergency procedures training) are assigned only to the appropriate devices (and the times properly accounted for), while transferable requirements may be satisfied by different combinations of devices, depending on the time available on each device.

ting, and maintenance costs over an economic comparison period. Figure 3 diagrams the overall process for determining life-cycle costs. The cost analysis adheres to current Air Force procedures for cost estimation for new procurements and employs the cost estimating model defined by the AFTEC Cost of Ownership Handbook. The major cost elements in the model are

- Acquisition costs
  - RDT&E
  - Engineering development
  - Procurement
- Operation costs
  - Operations manpower
  - Base system maintenance manpower
  - Base maintenance materiel
  - Miscellaneous personnel support
  - Utilities/fuel
  - TDY
- Base operating support costs
  - Base services manpower
  - Miscellaneous personnel support
- Logistics support costs
  - Depot maintenance manpower and materiel
  - Supply depot manpower and materiel
  - Second destination transportation
  - Technical order maintenance
- Personnel support costs
  - Recruit technical training manpower
  - Technical training cost
  - Medical manpower
  - Medical materiel
  - Permanent change of station
  - Miscellaneous personnel support
- Recurring investment costs
  - Replenishment spares
  - Recurring modifications (Class IV)
  - Common support equipment.

We examined both the acquisition and operating costs of aircraft and aircrew training devices to determine which costs can appropriately be "charged" to the training requirements. We concluded that we should include in each analysis of training cost-effectiveness only acquisitions dictated by the training requirements and only operating costs incurred or saved by particular training scenarios.

For example, for mission aircraft procured to satisfy a wartime mission requirement, it

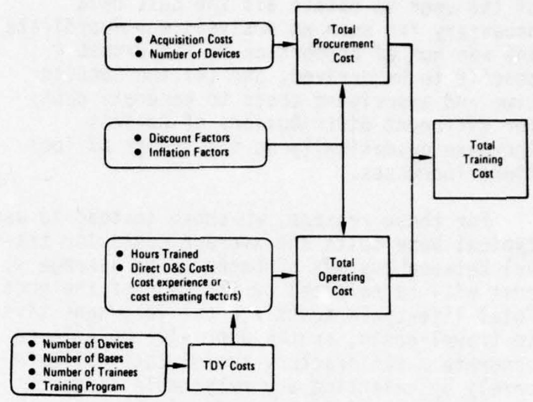

Figure 3
Cost Process

would be inaccurate to charge the acquisition costs for such aircraft to the total cost of a training program. However, for aircraft procured specifically for training programs, acquisition costs should be charged to the training program. (We note the latter assumption implies that the aircraft are not needed in a wartime environment; therefore, the consideration of tradeoffs between these training aircraft and simulators can be made without consideration of the constraints that a wartime mission requirement might impose. A detailed analysis of how mission aircraft procured for training would actually be utilized in a wartime emergency was beyond the scope of this study.) Similarly, base maintenance labor costs for aircraft which are established by the mission requirement would not be lowered by a reduction in flying time for training while those which are established by peacetime flying hours will be lowered by a reduction in flying time for training.

We examined the feasibility of comparing the differences in cost incurred by different distributions of devices among the locations (Air Force bases) of interest. These cost differences might be due to differences in TDY costs incurred for different distributions of devices, differences in operating costs at different locations, and consideration of economies of scale at a given base. However, a preliminary analysis revealed that such a level of detail was neither feasible nor highly desirable to an analysis of alternative sets of devices because: (1) the cost differences due to location are generally small compared to the cost differences due to different numbers and types of devices,

(2) cost data at the level of detail required for such an analysis (differences due to location and scale of operation) were not readily available, (3) the effort required of the user to obtain all the cost data necessary for such an analysis was inordinate and was out of proportion to the probable benefit to be derived, and (4) the computer time and associated costs to generate costs for different distributions of devices increase dramatically as the number of locations increases.

For these reasons, we chose instead to use typical base costs and average costs for travel between any set of bases. The average cost will be selected by the user of the model. Total life-cycle costs are not very sensitive to travel costs, so the user will be able to generate a satisfactory travel cost estimate merely by selecting any reasonable distance as the average (without resorting to a detailed knowledge of air fares and exhaustive compilations of interbase distances).

6. Output Processing

The above procedure subjects to cost and analysis only those alternatives that are effective. Therefore, following cost determinations, we can construct a matrix that contains some desired set of lowest cost alternatives and their associated life-cycle costs. The output processing phase of the model deals with ordering the life-cycle costs and displaying the desired number of alternatives. Outputs available include summary data of the costs of the most effective alternatives, and breakdowns of both the costs and utilization of each device type in these alternatives. The cost breakdown available allows an examination of annual and cumulative costs as a function of time and a determination of the relative contributions of procurement and operating costs. The utilization breakdown shows the time assigned to each device for each task and overall. The detailed cost and utilization data are useful in identifying parameters of interest for a sensitivity analysis, and in examining the consequences of a particular alternative in greater detail as a further aid to decision-making.

The output procedure facilitates performing a parametric sensitivity analysis. The effect on the cost-effectiveness of any variation in the value of any input parameter is determined by repetitive use of the model. The change threshold of parametric values (i.e., the point at which they begin to affect a given system) would be useful in designing, developing, and fielding a training system. Varying the system requirements for each training task can show the cost differences associated with achieving higher or lower levels of performance.

This paper reports research sponsored by the Air Force Human Resources Laboratory under Air Force Contract F33615-77-C-0072. The opinions expressed are those of the authors and do not necessarily represent Air Force official opinion or policy.

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PILOT PERFORMANCE IN THE VISUAL CARRIER LANDING TASK – SIMULATOR VS. FLIGHT

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INTRODUCTION

At the 6th NTEC-Industry Conference, 13 November 1973, I presented a paper on "New Approach to the Evaluation of Visual Attachments to Flight Simulators".[1] Some of the bases for the approach given then will now be re-emphasized, and an application to an in-house experiment will be presented.

Present methods of measuring performance characteristics of a visual attachment do not indicate whether visual cues which a pilot uses to perform a visual flight task are adequately presented to him. Lybrand in 1958,[2] stated that the best way of assessing a visual attachment is to have experienced pilots fly specific flight paths,and base rating on judgments of these pilots to supplement available evidence. By 1975 it was recognized by a Working Group of the Fluid Mechanics Panel of Advisory Group for Aeronautical Research and Development (AGARD), reference 3, addressing pilot performance and learning in simulated landings, that "the landing maneuver is subject to a number of direct performance measures. Particularly sensitive are measures at the instant of ground contact... . Landing performance measures (on the other hand) appear to uniquely correlate with subjective assessments...". However, this report did not provide a list of performance measures. As a result I went back to some World War II studies to identify objective pilot performance measures. These were developed in reference 1 and are repeated here:

a. Ratio of landing distance divided by distance from a designated point (runway end)

b. Landing attitude at touchdown

c. Index 1, elevator movement

d. Index 3, aileron movement.

The measures had correlation with graduation elimination criteria or could discriminate between groups having different amounts of training. The four measures selected had high repeatability or showed significant individual pilot differences. These are defined in Appendix A.

Normal acceleration was eliminated since most simulators at that time didn't have an exact analog of their landing gear bouncing on ground impact.

Rate of descent was eliminated because other studies showed that pilots have difficulty in judging rate of descent. Figure 1 from Palmer's paper at the 1973 AIAA Visual and Motion Conference[4] shows the effect of training on touchdown vertical velocity. With this variability, the measure is not dependable.

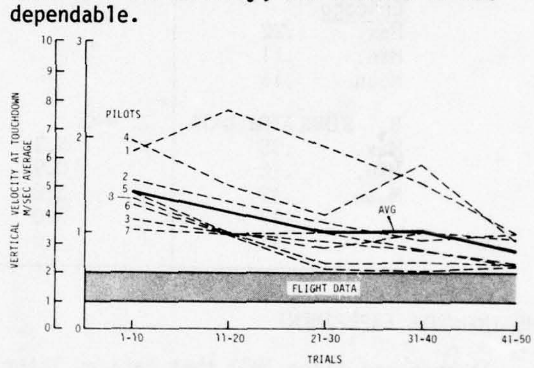

Figure 1. Effect of training on touchdown vertical velocity

Using existing flight and simulator data from Boeing 707 and KC135A test flights, the selected pilot performance parameters were used to relate to the adequacy of visual cues presented in the simulator visual attachment.

Table 1 from reference 1 shows a comparison of key parameters at a high gross weight for the Boeing 707 airplane.

The flight data is given at the top, the simulator data is given at the bottom.

For Index 1 the smallest value is 1.0 and represents no control movement.

For Index 3 the smallest value can be 0 and represents no control movement while the largest value can be 1.0 and represents the same number of movements as samples taken.

In Table 1 comparing flight test and simulator pilot performance, pilot performance in the simulator N matches pilot performance in the aircraft somewhat closer than that in simulator C.

I stated then that if I had data on later simulators and visuals for the Boeing 707 a closer correlation should have occurred.

TABLE 1
COMPARISON OF KEY PARAMETERS HIGH GROSS WEIGHT
(More than 150,000 Lbs.)

Point of Landing Touchdown Dist. / Runway Length	Landing Attitude Degrees	Index 1 Elevator	Index 3 Aileron	Simulator Designation
A. FLIGHT DATA				
.29	9.3	1.23	.815	
--	8.5	1.42	.89	
Max. .34				
Min. .03				
Mean .13	-	-	-	
S.F.				
Max. .27				
Min. .11				
Mean .19	-	-	-	
Chicago				
Max. .22				
Min. .11				
Mean .16	-	-	-	
B. SIMULATOR DATA				
Max. .35	5.3	4.50	.567	
Min. .10	0.9	2.00	.467	N
Mean .19	3.8	2.95	.507	
.17	3.0	1.50	-	D
.17	0	1.06	.944	C

THE IN-HOUSE EXPERIMENT

It appeared since 1973 that data on later simulators was not available and therefore I would have to collect my own data. There existed at the NAVTRAEQUIPCEN in 1973 an in-house flight simulator with a visual system which could be used to conduct the validation experiment. The experimental facility arrangement is shown in Figure 2. A description and the performance of the sub systems follows:

The gantry, optical probe and the T-28 flight simulation were described in the 11th NTEC-Industry Conference Proceedings[5] and will not be repeated. The model for the image pickup was a three dimensional model of the CV-59, U.S.S. Forrestal, at a scale of 250:1, complete with the Fresnel Lens Optical Landing System (FLOLS) display unit, and illuminated by a number of high intensity lights. These were used previously in Device 2H87, Aircraft Carrier Landing Trainer. The details are shown in Figure 3. The carrier image was projected in front of the pilot by means of a G.E. color TV Projector, Model PJ500 onto a standard movie screen located so as to provide a 60° horizontal field of view picture directly in front of the pilot seated in the simulator cockpit. The television picture was generated by a Cohu color TV camera model coupled to the optical probe. The FLOLS activation simulation is based on the model described in reference 6. The subjects were six pilots assigned to NAS Cecil Field, Jacksonville, Florida, qualified in A-7 aircraft.

RESULTS

The premise as stated in reference 1 is that the proper method for evaluating the adequacy of a visual attachment to a flight simulator is to measure the pilots' effort in performing a specific task in the simulator and compare it with the effort expended doing the same task in the real world. Any large difference would indicate, provided the flight simulator characteristics are represented adequately, that the amount of visual information presented to the pilot external to his cockpit is different between that shown in the simulator and that shown in the real world flight.

The subject pilots flew 2 practice flights and 5 test flights for daytime conditions and 5 for night conditions. Only the daytime flights will be discussed as only daytime results are available from actual carrier landings. This performance in the simulator would be compared to that of pilots' performance obtained in landings on board carriers.

Flight test data was obtained from two cruises reported in references 7 and 8. The CVT-16, U.S.S. Lexington, in the Gulf of Mexico in 1968 and the CV-42, U.S.S. F. D. Roosevelt, in the Atlantic off the coast of Florida in 1965. Earlier data from the Naval Air Test Center (NATC) landings on

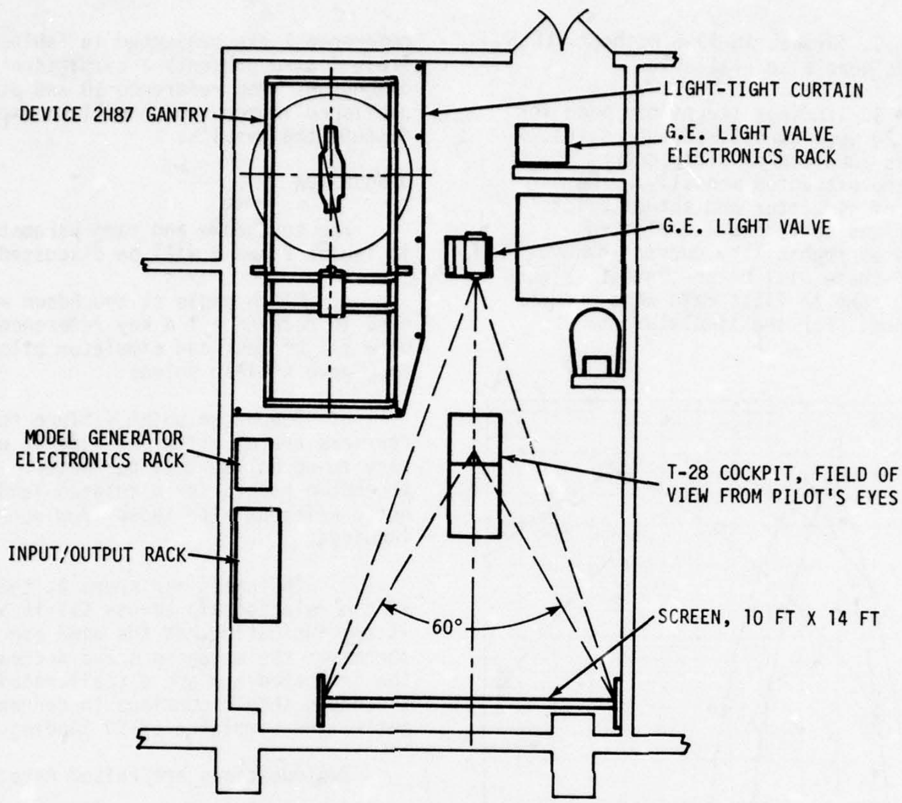

Figure 2. Experimental Facility Arrangement

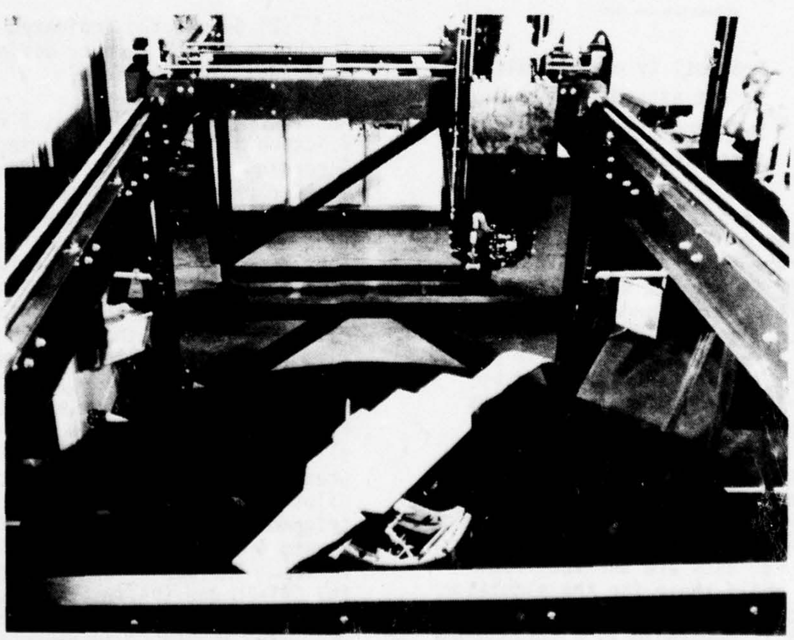

Figure 3. Camera and optic probe gantry system with the optic probe just above and behind the carrier

CVS-40, U.S.S. Tarawa, in 1955 without FLOLS, reference 9, were also available.

Of the 30 landings the pilots made for recording, 20 were considered successful. The data was recorded on strip chart recorders and extracted manually. The comparison of simulator and actual pilots' performance was performed and plotted graphically as probability curves; however, only one of these will be presented. Figure 4 shows the ramp to first main wheel touchdown distance. For the simulator the

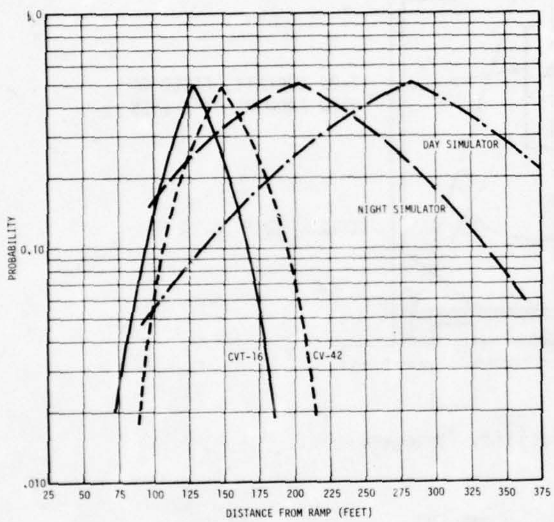

Figure 4. Probability of exceeding or not exceeding ramp to 1st wheel touchdown distance (main)

touchdown distance was determined by freezing the optical probe at an altitude of 65 feet above the water (the pilot's eye position in the aircraft on deck) and finding the proper distance along the deck corresponding to the freeze time point on the strip chart. The flight test results were obtained by analysis of calibrated photographic films of the landings.

Pitch angle was either derived from the photographic analysis (flight test) or from the measured value on the simulator recorder. The angle of attack and the indicated air speed for flight tests are derived from recorded data while those for the simulator are computer outputs. The lateral position along the deck is developed as described for touchdown distance.

Landing parameters as proposed in reference 1 are presented in Tables 2 and 3. Table 3 also presents a comparison of carrier dimensions from reference 10 and other published sources which will be used to discuss the results.

DISCUSSION

The touchdown and ramp parameters shown in Tables 2 and 3 will be discussed.

a. Pitch angle at touchdown was considered in reference 1 a key reference parameter. Both flight test and simulator pilot performance gave similar values.

b. Touchdown point - Since the aircraft carriers are of different size it was necessary to normalize this parameter. Normalized touchdown points for simulated landings are not consistent with those from operational landings.

c. Indicated air speed at touchdown - If the relationship across CVT-16 and CVA-42 is any indication, as the wind over deck increases the engaging speed decreases, and the indicated air speed (calibrated value) at touchdown should continue to decrease as we get to the simulated CV-59 landings.

Two questions are raised here:

(1) Should the mean distance to touchdown be the same or different for the different size carriers?

(2) Should the indicated airspeed at touchdown be the same or different for the different size carriers?

To answer these questions, I reviewed Brictson's analysis of carrier landings. According to Brictson in reference 11 and his earlier reports, there should be no difference in landing difficulty between FLOLS settings of 3.5^{o} and 4^{o} on large carriers. Landings on the large size carriers should be slightly better than on the medium size carriers. While on day landings, pilots approach above the glide slope path, they land short of the target wire (#3). If a pilot maintains a high approach (above the normal glide slope) he will land long on the deck (#4 wire or a bolter). On the other hand reference 12 states that the shallower the glide slope becomes, that is from 4^{o} to 3^{o}, the greater the dispersion in touchdown point with pilot glide slope error due to the simple trigonometric relationship. This is shown in Figure 4 as a greater spread in the simulator curves. The actual aircraft glide angles for the CVT-16 and CVA-42 landings exceed the on glide slope glide angle by about 2^{o} (steeper), while for the CV-59 landings the actual glide angle is about $.7^{o}$ lower than theoretical (shallower).

TABLE 2
COMPARISON OF T-28C LANDINGS
(MEAN VALUES)

	CVT-16	CVA-42	SIMULATED CV-59
PITCH ANGLE AT T/D (Degrees)	6.24	5.51	6.7
AIRCRAFT GLIDE ANGLE AT T/D (Degrees)	4.4	4.39	.3
ANGLE OF ATTACK AT T/D (Degrees)	10.64	9.9	7.0
ENGAGING SPEED (KTS)	65.10	62.10	58
WIND OVER THE DECK (KTS)	19.5	21.2	30
INDICATED AIR SPEED @ T/D (KTS)	84.6	83.28	88
LATERAL POSITION AT T/D (Feet) (+ is port)	- 4.05	3.39	7.0
DISTANCE RAMP TO 1st WHEEL CONTACT (Feet)	129.57	148.8	283
PRINCIPAL WIRE ENGAGED	2	2	4
OPTICAL GLIDE PATH (Degrees)	4	4	3
NUMBER OF LANDINGS	42	100	20
PITCH ANGLE AT RAMP (Degrees)	3.45	3.34	
HOOK HEIGHT ABOVE RAMP (Feet)	9.65	10.37	-
MAIN WHEEL HEIGHT ABOVE RAMP (Feet)	12.29	13.39	-
PILOT HISTORY	UPT CARQUAL Min. of 150 Flight Hours	REPL. SQ. CARQUAL	FLEET A-7 Pilots

TABLE 3
COMPARISON OF NORMALIZED LANDING AND CARRIER PARAMETERS

	CVT-16	CVA-42	CVA-59	RUNWAY
RATIO: MEAN TOUCHDOWN DISTANCE TO CANTED DECK LENGTH	.24	.28	.41	.40
ELEVATOR CONTROL INDEX NUMBER 1	-	-	1.026	1.38
AILERON CONTROL INDEX NUMBER 3	-	-	.276	.34
RATIO: 2nd WIRE DISTANCE TO CANTED DECK LENGTH	.24	.28	.24	
RATIO: 3rd WIRE DISTANCE TO CANTED DECK LENGTH	.30	.32	.29	
RATIO: RAMP TO FLOLS DISTANCE BY CANTED DECK LENGTH	73	.80	.62	
CANTED FLIGHT DECK LENGTH RELATIVE TO CVT-16	1.00	1.00	1.27	
OVERALL FLIGHT DECK LENGTH RELATIVE TO CVT-16	1.00	1.09	1.17	

No discussion in the literature addresses the variation in touchdown airspeed; however, since the glide angle is lower the airspeed should be higher. Another factor probably contributing to the higher speed is that the simulated landing scene did not provide any texture, such as waves, to the blue water as projected on the screen. This omission on other visual simulations has been reported as a negative cue to judging speed over the water on approaching the carrier. However, airspeed is not a key parameter.

The discrepancy in touchdown distance leads to a re-examination of the visual cues. The computation of the FLOLS setting may be seen from the details in Figure 5. The apparent lens location was set by placing the optical probe at the #3 wire touchdown point and extending the glide slope line at 3°. The display of the glide slope in the simulation was with a three lens display, instead of the normal five lens display, located at a full scale height of 40 feet above the deck vice being flush with the deck level as in the operational situation. That is, Δh instead of being 10 feet below deck level was actually 30 feet above deck level. If the pilot followed the FLOLS indications, he would probably land at the correct wire at night because of minimum ship-shape cues, but in the daytime landing the on-glide-slope as presented would place the aircraft meat ball 40 feet higher over the ramp than normally. The pilots' prior experience in carrier landings would cause them to expect to see more of the carrier deck above the aircraft forward cockpit cowling than was visible as projected on the screen. The conflict in cues between the simulated situation (following the FLOLS) and the actual (60 feet above the ramp), would become apparent.

A comparison of pitch angle over the ramp for the actual landings and the simulated landings showed that for 10 of the 20 successful simulator landings the pilots were diving for the deck ($-.5^{\circ}$ versus 3.4°). This would seem to indicate that the pilots were trying to correct the discrepancy in height at the ramp. Table 3 also shows touchdown distances obtained by a NASA test pilot landing the T-28 aircraft on a 5000 ft. runway. This touchdown point compares well with the landings on the CV-59, thus again confirming shallow glide path.

d. Lateral position at touchdown appears to be consistent in magnitude between actual landings and the simulated ones. The interpretation here is that steering or lateral aligning information was adequate in the simulation.

e. Elevator Control Index Number 1 and Aileron Control Index Number 3 were again difficult to obtain from the flight test. The flight test data available was from stalls and runway landings and was a substitute for data for carrier landings. For both indices the simulated landings required less control movement. The differences between the T-28 data is less than the differences shown in

PARAMETER	DEFINITION
X'_o	APPARENT MEATBALL LOCATION
Δh	VERTICAL LOCATION OF IMAGE
h_o	HOOK-TO-EYE DISTANCE

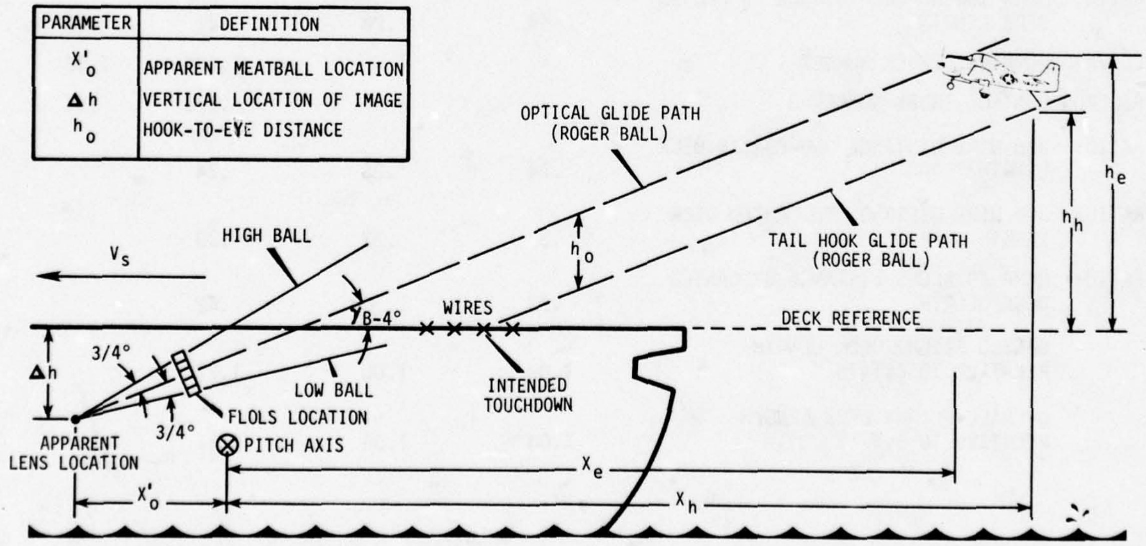

Figure 5. FLOLS relationships

Table 1 for the Boeing 707 data. Pilots flying the simulator did not complain about its flying characteristics. It was also used and was acceptable for the experiment reported in reference 5.

f. Normalized carrier dimensions show individual carrier differences which are not consistent with change in size and probably contribute to the variations in landing distance.

CONCLUSIONS

The results of this experiment tentatively support the hypotheses by showing that errors in the simulation do contribute to differences in pilot performance. The differences in landing distances can be explained by the consistent variation in other parameters such as glide path, pitch angle at the ramp, and landing speed.

The principal errors in simulation were the vertical location of the FLOLS and the lack of texture in the water. Steering alignment was satisfactory. If the computational and physical differences account for most of the differences, then the original hypothesis that the comparison in pilot performance can identify the visual cues differences in the visual attachment is valid. It is again recommended that another comparison be performed with better simulation so that this hypothesis can be adequately tested.

REFERENCES

1 Aronson, M., "New Approach to the Evaluation of Visual Attachments to Flight Simulators," Proceedings of the Sixth NTEC/Industry Conference. Naval Training Equipment Center NAVTRAEQUIPCEN IH-226, November 13-15, 1973 (AD 768756), pp. 382-387.

2 Lybrand, W. A., Havron, M. D., Gartner, N.B., Scarr, H. and Hackman, R. C., "Simulation of Extra-Cockpit Visual Cues in Contact Flight Transition Trainers," AF-PTRC-TR-58-11, February 1958 (AD 152123).

3 Approach and Landing Simulation. AGARD Report 632, October 1975 (AD-A0 18179).

4 Palmer, E. A. and Cronn, F. W., "Touchdown Performance with a Computer Graphics Night Visual Attachment," AIAA Paper Number 73-927, AIAA Visual and Motion Simulation Conference, Palo Alto, California, September 10-12, 1973.

5 Aronson, M., "A Low Cost Simulator for Air-to-Ground Weapons Delivery Training," Proceedings of the 11th NTEC/Industry Conference, Technical Report NAVTRAEQUIPCEN IH-306, November 14-16, 1968, pp. 227-235 (AD-A0 61381).

6 Golovcsenko, Igor, "Computer Simulation of Fresnel Lens Optical Landing System," Naval Training Equipment Center Technical Report: NAVTRAEQUIPCEN IH-265, September 1976 (AD-A0 38456).

7 Swierczynski, R. F., Statistical Presentation of Landing Parameters for Models T-2B, TS-2A and T-28 Aircraft Aboard the U.S.S. Lexington (CVS-16) and for Model T-2B Aircraft at Sherman and Bronson Fields, NAS Pensacola, Florida, Naval Air Development Center Report ST6810 (AD 847902).

8 Catanese, R. M., Statistical Presentation of Landing Parameters for Models F-4B, RF-8A, F-8E, A-6A, T-2A, T-28C, TS-2A and C-1A Aircraft Aboard the U.S.S. F. D. Roosevelt (CVA-42), Naval Air Development Center Report ASL-1089 (AD 487477).

9 ________ Service Acceptance Trials of the Model T-28C Airplane, Carrier Suitability Phase, Letter Report No. 1, Final Report, NATC Project No. BIS 21195, FT35-9, 24 January 1956 (AD 87627).

10 Technical Manual - Installation, Service, Operation and Maintenance Instructions, Fresnel Lens Optical Landing System, MK6 MOD 0, NAVAIR 51-40ABA-1, 1 October 1964.

11 Brictson, Clyde, Burger, William J., Wulfeck, Joseph W., Validation and Application of a Carrier Landing Performance Score: The LPS, Interim Technical Report, Dunlap and Associates, Inc., Western Division, March 1973 (AD 910514).

12 Nelson, J. H. and Griffin, G.M., United States Navy Pilot-Controlled Landing Procedure and Associated Equipment AGARD Report 423, January 1963.

APPENDIX A

Definition of Parameter Terms:

Point of Landing - Distance from approach threshold of runway to point of first wheel contact; made non-dimensionsal by dividing by runway length. If pilots recall their training, they were taught to land within the first third of the runway. Since aim point is selected by proportion then absolute distance is immaterial.

Landing Attitude - Inclination of Fuselage Reference Line to Runway At First Wheel Contact:

Index 1, Total Amount of Elevator Control Movement - calculated by running a "Map Measure" along the graphed line plotted to show wheel column (or stick) movement (affecting elevator adjustment). This provides a measure of the total length of the line representing movement (i.e. successive positions) of the control. In order to compensate for differences in total time of the maneuver as carried through by various pilots, the obtained measure was divided by the length of the straight line across the graph, which would be obtained in plotting if the control was held in a constant position, without movement, throughout the maneuver.

Index 3, Number of Aileron Control Movements - Provides a quantitative statement of the total number of discrete control movements (aileron) during the maneuver. These movements are of four types: Left to Right, Right to Left, Stationary to Left and Stationary to Right. The index is obtained by dividing the total number of control movements by the total number of readings for the maneuver.

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USING THE MICROPROCESSOR TO TAILOR COMPUTER SYSTEMS TO TRAINING SIMULATOR REQUIREMENTS

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Educational Computer Corporation

INTRODUCTION

The advent of the microprocessor has ushered in a new era of computer applications. The power and economy of the microprocessor opens entire new fields for computer applications and will change many existing techniques that now use mini and full scale CPU. It is this power and combined economy that allows the microprocessor to be tailored to each particular application rather than fitting system requirements to existing processors.

Educational Computer Corporation's use of multiple microprocessors in a "Federated Multiprocessing Architecture" is an example of tailoring the processing system to fit the application. It also represents changing an existing minicomputer application. The EC 3, as was its predecessor, the EC II, is specifically designed to accommodate the requirements of simulator operation. However, the microprocessor has provided the EC 3 a multifold increase in capability and power, plus a decrease in mainframe hardware costs.

Though the hardware cost has been reduced and subsequent software operational languages have, as a result, been made more efficient and powerful, the cost of preparing the simulation, if not controlled, can become much greater than in previous applications simply because of the added or increased capability of the simulation system. This requires that the simulation requirements specifications be precisely controlled.

The range of requirements that were considered in the design of the EC 3, the resultant microprocessor system structure, and some of the applications to which it has already been put are also discussed.

VERSATILITY OF THE MICROPROCESSOR

The microprocessor has often been heralded as a device that will create our next technological revolution. It is already replacing mechanical timers and integrators. It will change engineering application techniques and allow the development of new devices not economically feasible before. Some of this is already happening. We've already seen the cost of hand-held calculators come down while their function capacity increases; video games, children's toys, the home computer, and educational games are the more obvious commercial applications. In the industrial area there is a less obvious, but nonetheless broad application of the microprocessor: the auto industry, cameras, machine tool design, word-processors, test instrumentation, portable devices of all kinds. In the military there is a similar growth of application, especially in test devices, electronic systems, avionics, and training equipment.

This wide-spread application is made possible by the combination of computational power, size, and low cost of the microprocessor. As many as are needed can be put almost anywhere and without significant expense. This is the significant feature of the microprocessor -- its applications adaptability. Processing requirements can be more readily tailored to meet application requirements than is possible with processors available up till now -- namely the minicomputer.

APPLICATION AT EDUCATIONAL COMPUTER CORPORATION

The microprocessor has provided Educational Computer Corporation a means to capitalize upon our original concept of simulator design. The predecessor to the EC 3, the EC II, utilized a special purpose mini-computer of our own design. It was a logic processor, akin to a sensor based, or process-control system, capable of handling some 96 inputs and 96 outputs within a 58 microsecond cycle time frame. It was not a commercial, scientific or data processor. It was unique in that it was designed exclusively to support our simulator requirements. The software was also unique in that it related directly to the functions of the simulation which demands a diversity of input/output (I/O) and a high degree of logic complexity.

The EC 3 is both a continuation and expansion of that philosophy, but instead of being limited by the processor, the processor is now a system utilizing multiple processors that support all the requirements prescribed for the simulator. The microprocessor has also enabled the projection disk slide capacity to be increased from 100 to 150 with an access time of less than 500 ms.

SIMULATOR DESIGN CONSIDERATIONS

In designing a training simulator a choice has to be made by the designer. Either he choses off-the-shelf, commercial hardware and its accompanying software, or he makes his own. Choosing the former he has a computer, but it is a data processor, and not optimum for what he really needs It can do what it is designed to do, but can't do enough of what is required as a simulator controller. The greatest problems occur between internal and external operations and the "systems overhead" incurred by using available high level languages.

The simulator designer also has trouble communicating with the scientific or data processing computer. The languages available were designed for typical computing purposes, such as data handling and scientific processing, not extensive logic function handling. Hence, it takes longer to prepare source code programs and they, in turn, are generated into still less efficient machine code programs. These use up memory unnecessarily, take too long to run, and are cumbersome to control -- both from the programmer's viewpoint and logistically. They also take longer to test and debug because of the additional code.

To make the other choice, designing his own computer, the simulator designer must make a long term commitment. And he must understand the requirements that will be created for his simulator. Not only will he be devising a computing capability, but he must also devise a means to effectively communicate with his computer and then use it efficiently. This means creating his own software languages to match his computing system.

Prior to designing the EC II,a minicomputer driven simulator which preceded the EC 3, ECC had experience with its hardwired simulator, the SMART. We therefore knew what kind of computer was needed and how we had to describe the simulation; i.e., how we would have to communicate to the processor. But, there was a problem, we tried using FORTRAN and BASIC. There was nothing available that could do what we wanted. We built our own computer and created our own language. That was 1970. We were sticking our necks out, but soon we were using all our available I/O (96 Input and 96 Output lines). Even multiplexing. Memory increased from 4K to 12K, and in a few cases to 16K.

In 1974, we started research on a redesign. We started with a microprocessor and, in fact, built some so-called "hardwired" devices which in reality utilized a microprocessor and a ROM chip for memory. Figure 1 shows one of these "stand-alone" simulation models.

Then in 1976, we produced the EC 3 which uses four or more microprocessors. Though we don't build the processors themselves as we do for the EC II, we have structured them to satisfy our requirements and we are achieving results we would not be capable of with standard off-the-shelf systems.

STRUCTURE OF THE EC 3 COMPUTER SYSTEM

In designing the EC 3 computer system, ECC design engineers had to consider all the potential requirements that would be placed on the system. As already mentioned, the requirements of a computer-controlled simulator are more like those of a process-control or sensor-based system rather than like those of a commercial or scientific data processing system. A simulator-controlling computer has a relatively limited data movement and numerical computation requirement. But it must have the capability to handle a high volume of diverse I/O requirements and be able to economically and quickly handle large complex logic models in a Boolean format.

Commercial, off-the-shelf, processing systems and their associated high-level languages are designed for scientific or business applications, and perform poorly in handling process-control or sensor-based system requirements. The EC 3 hardware, firmware, and software, were tailored from their inception to provide the optimum simulator capability.

The design effort had to also take into account the requirement for a multitude of unknown peripherals or special devices that may be configured on the system to meet some future requirement. In the EC 3, separate processors have been incorporated to simplify system management and peripheral growth. ECC software has been designed to manage the configuration, which results in more efficient programming and memory usage. This in turn reduces the time and cost of programming.

Since the development of high density, integrated circuits, the major cost of any computer system is in soft-

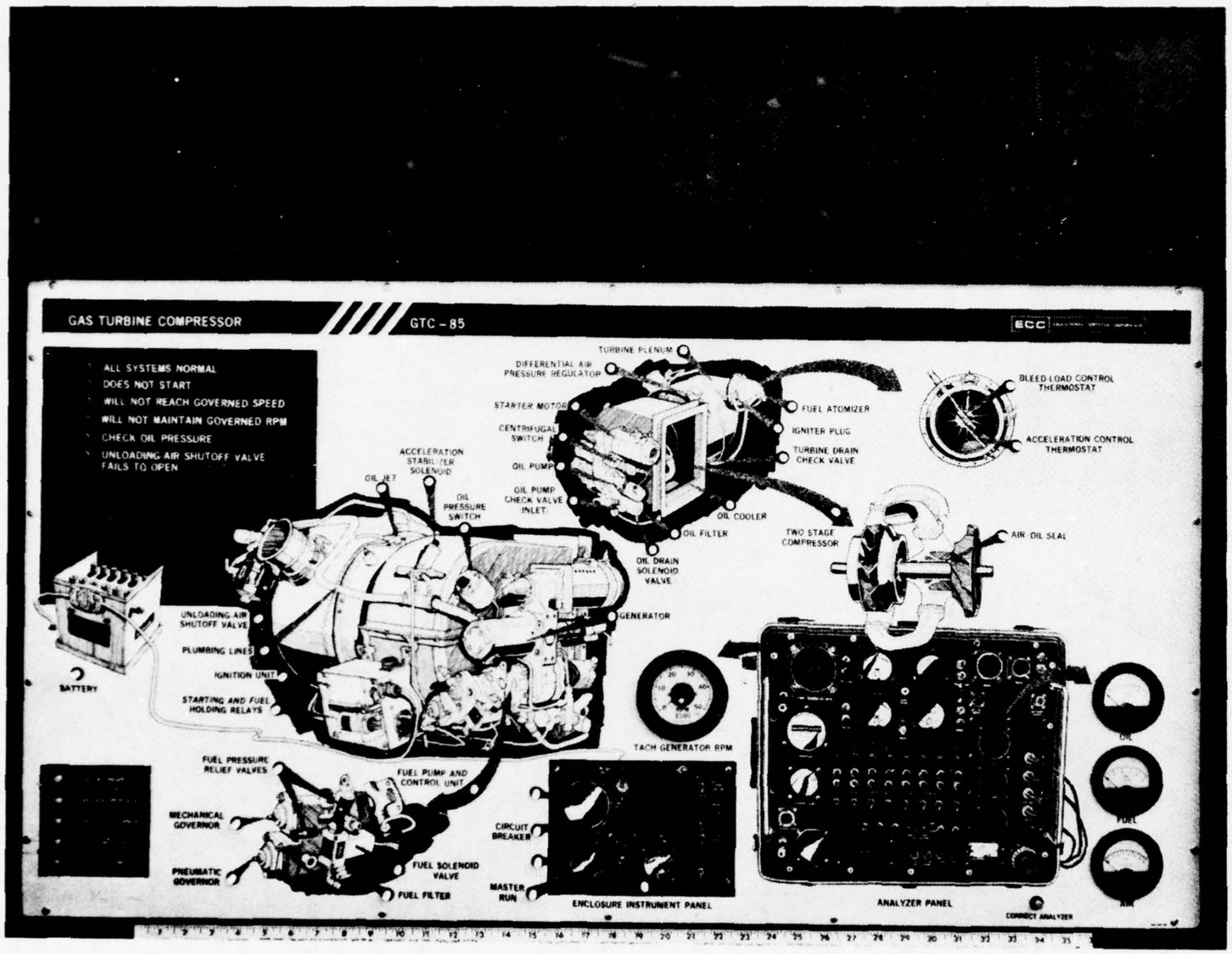


Figure 1. GAS TURBINE COMPRESSOR (STAND ALONE)

ware development. Hence, the hardware design in a total system development must enable programming to be as simplified and efficient as possible.

Unlike commercial data processing systems which utilize one central processing unit, the EC 3 employs multiple microprocessors in a "federated multiprocessing architecture." The executive processor is free for the processing of the mainline program while channel interrupts, control and scheduling are handled by the auxiliary processors. Peripherals requiring constant attention by the EC 3 are handled by dedicated or rapidly multiplexed processors which communicate through shared memory, making data transfer essentially transparent.

Where I/O operations are time consuming or complex, such as transfer between controller and memory or moving simulation panel instrumentation, these operations are controlled by separate auxiliary processors. With data transfer at full operational speed via shared memory, the executive processor is freed from I/O transfer wait time and can concentrate its resources on processing the main simulation program.

The EC 3 processing system can test or set a large number of Boolean I/O devices in one instruction cycle with no set-up or "handshaking" required. This is an order of magnitude faster than single-bit I/O implementation used by the commercial data processing systems. The EC 3 also places I/O ports in specific memory locations so the vast majority of I/O devices are treated as data types in the EC 3 programming language. This reduces the assymetry between internal and external operations and much of the "systems overhead" incurred by compilers such as FORTRAN or COBOL . This capability, which is unique to the EC 3, not only reduces memory required for a simulation model program, but also reduces processing time by elimination of I/O control operations which, by themselves, do not produce meaningful results.

Programming efficiency and operational time is enhanced by PROM resident within the EC 3 operating system. This eliminates utilizing memory for the standard I/O drivers (CRT, Teletype, Diskette drive, etc.). PROM is also used for basic system diagnostics and common sub-routines such as arithmetics, integrations, text handling and error reporting. PROM storage protects critical and commonly used program routines from loss due to power failure and especially inadvertent modification by the user. With only the main line application program resident in the RAM, savings are realized with reduced programmer coding and optimization of the RAM.

PROGRAMMING

ECC's prior experience with simulation controllers, including the use of commercial hardware and software, had already proven that most simulation programming time and cost was associated with operations that could easily be described through concise Boolean statements. (In fact, a major portion of the EC II and EC 3 programs is a series of Boolean equations.) These operations are the ones most poorly implemented using commercial languages. Even with languages such as FORTRAN, in which it is possible to write Boolean equations ("TYPE LOGICAL"), the implementation penalty is severe. The EC 3 is designed specifically to handle Boolean equations and single bit I/O rapidly and efficiently and the EC 3 compiler maximizes the use of this capability. (Logic design engineers use Boolean algebra statements in the description of logic problems and logic systems design.)

If the system being simulated is able to be described with Boolean statements it can be directly implemented on the EC 3.

Random Access Projector

The Random Access Projector (RAP) used in the EC 3 might be called a "SMART" projector in that it has its own microprocessor. The first of these projectors built by ECC, (RAP I), were controlled directly by the processor. Later models, RAP II and RAP III, do by themselves, what the computer system asks. Here again is an application of the microprocessor.

In order to provide a high degree of availability and rapid random slide selection, the slides on the disk are arranged in a spiral on a transparent disk which rotates over a fixed light source while it traverses laterally. Originally the slides were placed along fixed radii

of the disk with considerable space being wasted in the outer coils of the spiral. Now that space is able to be condensed with the microprocessor keeping track of all the slide positions. It simply "knows" where it is all of the time.

Prior to using the microprocessor in the projector, the computer system had to track the position of the visual disk and send positioning commands to the projector through an interface. Now the computer system simply asks for a slide position and the projector takes care of itself. This also allows the RAP III projector to be used as a stand-alone device or easily interfaced with some other system.

EC 3 SYSTEM

ECC developed the EC II primarily as a device to provide procedural and diagnostic (troubleshooting) training for the maintenance technician trainee. The EC 3 has been designed for these same applications and beyond. It is able to interface to actual equipment, operate CPT's (Cockpit Procedures Trainers), perform detailed intermediate level maintenance simulation and provide CAI and/or CMI support.

The EC 3 system consists of a mainframe or console which houses the computing system and control console and then, as required, additional peripherals: CRT, visual display, printer, or other display device.

Figure 2 shows the typical,individual system console which contains the power supply, diskette, computer system, projector, projection screen, and system control console. Figure 3 shows the computer system console connected to a large classroom display panel. Figure 4 is a detailed view of the Control Center.

The computing system is designed as a general purpose simulator control and becomes a system specific trainer with the addition of a simulation model. A standard simulation model consists of a unique display panel on which is presented a modified two-dimensional pictorial or schematic of the real equipment, a magnetic diskette on which is stored the simulation computer program, a visual display disk or 35mm slide tray, an instructor's guide and, where necessary, auxiliary equipment such as meter probes.

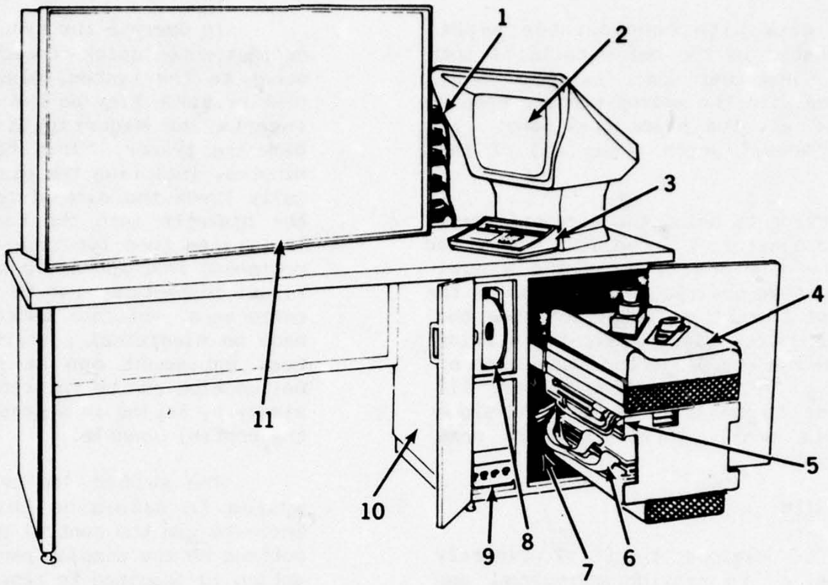
To operate the system, the student or instructor quick-connects the display panel to the system, places the visual disk or slide tray on the projector, and inserts the magnetic diskette in the diskette reader. This takes about two minutes. Inserting the diskette automatically loads the simulation program from the diskette into the computer memory. The system then functions as the actual equipment in response to student actions. Visual inspections can be made of various components, volt/ohm meter tests can be made on electrical circuits and special test equipment can be simulated. A malfunction can be entered in the system simply by keying in a predefined code on the control console.

The student can troubleshoot the system to determine the problem and indicate via the control console or entry buttons on the display panel what remedial action is required to repair the system. While the student is operating the system, records are maintained by the system of elapsed time and the number of tests or replacement actions taken by the student.

If program changes are required, they can be made either by ECC or the user.

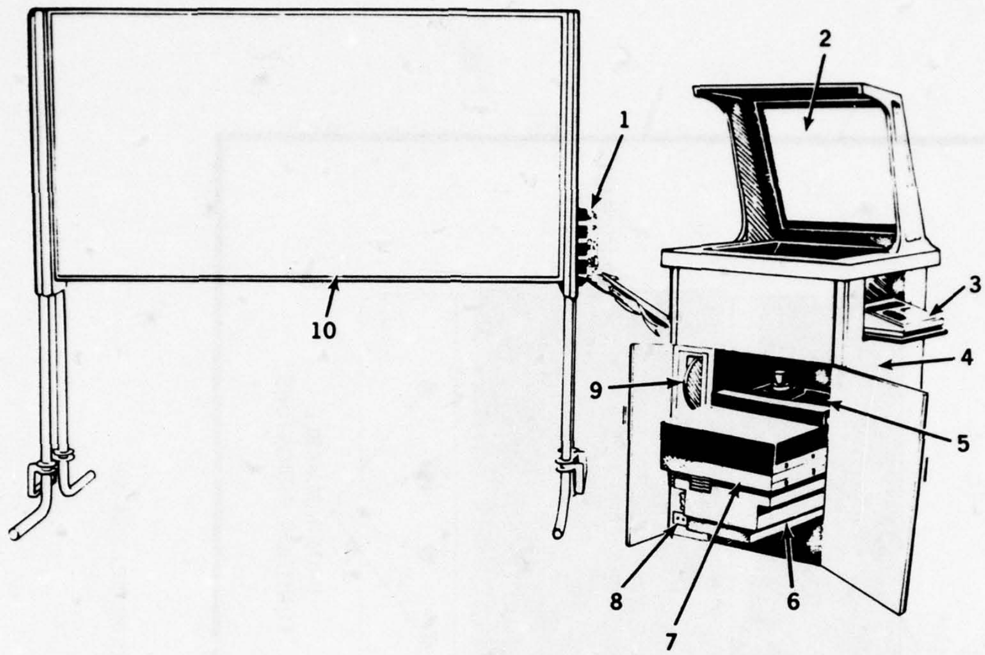
The typical EC 3 application is to provide a panel with a pictorial of the system or part of the system for which training is being given. Within the pictorial rendering are all the controls and test equipment, meters, displays and so forth that a technician would use if he were working on the actual equipment in the real world. The student can then operate the system just as he would in actuality and the simulated system will respond.

He is provided simulated test equipment and can use, for example, probes from his simulated VOM or oscilloscope in jacks or at test points that are actually represented on the simulation. For those actions which can't actually be performed, the student is provided pushbuttons which replicate the results of that action. For instance, if he wanted to visually inspect a component on the projector screen he presses a visual inspect button and then a button at the component he is inspecting. If the system was simulating a malfunction mode and that component would in actuality appear abnormal, he would see a picture of the abnormal component. If he is using the



1. DISPLAY PANEL CONNECTORS
2. VISUAL PROJECTION SCREEN
3. EC3 CONTROL CENTER
4. RANDOM ACCESS PROJECTOR
5. EC3 COMPUTER SUBSYSTEM
6. SYSTEM ELECTRONICS
7. SYSTEM POWER SUPPLY
8. PROGRAM DISKETTE DRIVE
9. CIRCUIT BREAKERS
10. EC3 CONSOLE CABINET
11. SIMULATION DISPLAY PANEL

Figure 2. INDIVIDUAL EC 3 SYSTEM



1. DISPLAY PANEL CONNECTORS
2. VISUAL PROJECTION SCREEN
3. EC3 CONTROL CENTER
4. EC3-LP CONSOLE CABINET
5. RANDOM ACCESS PROJECTOR
6. SYSTEM POWER SUPPLIES
7. EC3 COMPUTER SUBSYSTEM
8. CIRCUIT BREAKERS
9. PROGRAM DISKETTE DRIVE
10. SIMULATION DISPLAY PANEL

Figure 3. LARGE PANEL EC 3 SYSTEM

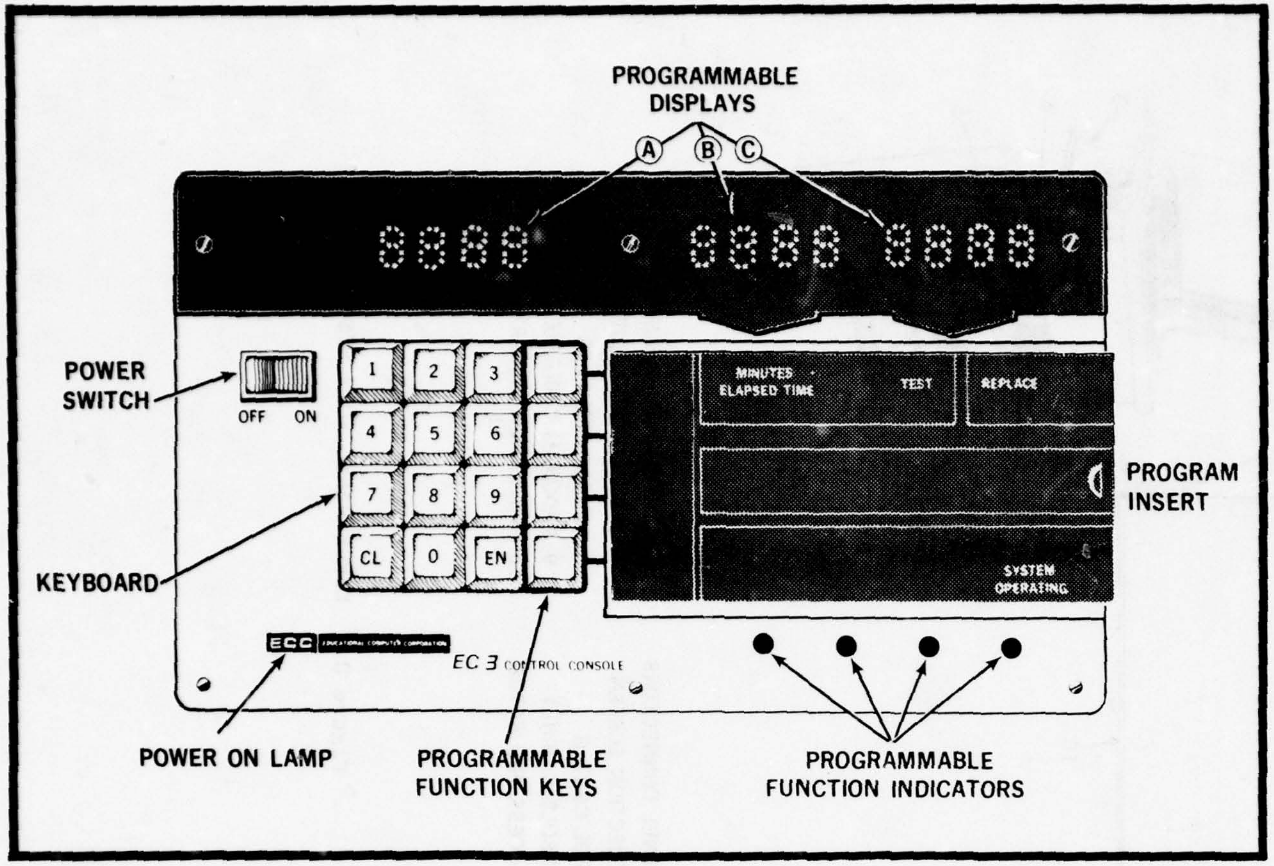


Figure 4. EC 3 CONTROL CENTER

simulation in a normal configuration and does something which would create an abnormality, the simulation would respond accordingly.

The panel simulations present prime equipment systems in a reduced physical fidelity format, but with full functional fidelity. If the training requirements dictate that the simulation have full physical fidelity, then instead of a panel, a three-dimensional representation is used. Figure 5 is a 3-D simulation of a tank turret system trainer.

How the simulation operates is determined by the training analyst. For instance, whether or not the student is given cues or admonitions is dependent upon the training design requirements. And if required, these can be changed under program control as the student advances and becomes more proficient. Figure 6 shows a specific simulation application. It is a simulation incorporating a TSGMS (a test set) for trouble-shooting the TOW Missile System on the COBRA helicopter.

EC 3 FEATURES

Standard Features

SYSTEM

- o Multiple Microprocessors (four)
- o 16K Dynamic Random Access Memory (RAM)
- o 9K Programmable Read Only Memory (PROM)
- o 512 words static RAM
- o Multiple RS232 communication input/ouput ports
- o 256 input lines/128 output drivers
- o 64 discrete lines for simulated probe points
- o 8 Digital/Analog - 8 Analog/Digital Converters

RANDOM ACCESS VISUAL SYSTEM

The RAP III projector, a high reliability display device, stores 150 images on a 9-inch plexiglass disk. Access to visuals for display is under computer control. Average access time is less than half a second, with maximum access time from position 01 to position 150 of approximately 2 seconds. The RAP III, with its own microprocessor, can be used as a stand-alone device or interfaced with other systems.

DISKETTE

An IBM compatible diskette with 256K words of storage is used as the program storage media. The use of a direct access storage device permits easy configuration of an EC 3 system for CAI/CMI applications.

SNAP ON SIMULATION DISPLAYS

Quick disconnect-connect receptacles are used for the interchangeable simulation models. The individual trainer panels are standardized in size, but classroom system panels are varied dimensions. In training situations where three-dimensional test equipment or additional panels are required, multiple panels can be cable-connected to one main panel attached to the system.

CONTROL CONSOLE

- o Digital Keyboard for entry of student information and preprogrammed conditions
- o Special Alphanumeric Functions for multiple choice testing results
- o 12 LED Condition Display for instructional feedback, in monitoring elapsed time, student performance, or special tracking
- o System Operating Condition Display, including audible tone warning signal

Optional Features

ADDITIONAL:

- o Diskette Units
- o D to A/A to D Converters (increments of 8)
- o Input/Output increments of 256 inputs; 128 outputs, 64 discrete lines

RAM MEMORY

- o Expansion from 16 to 56K in 4K increments

CRT DISPLAY

- o 1024 characters on a 7x9 inch screen for Computer Aided Instruction or Systems Programming

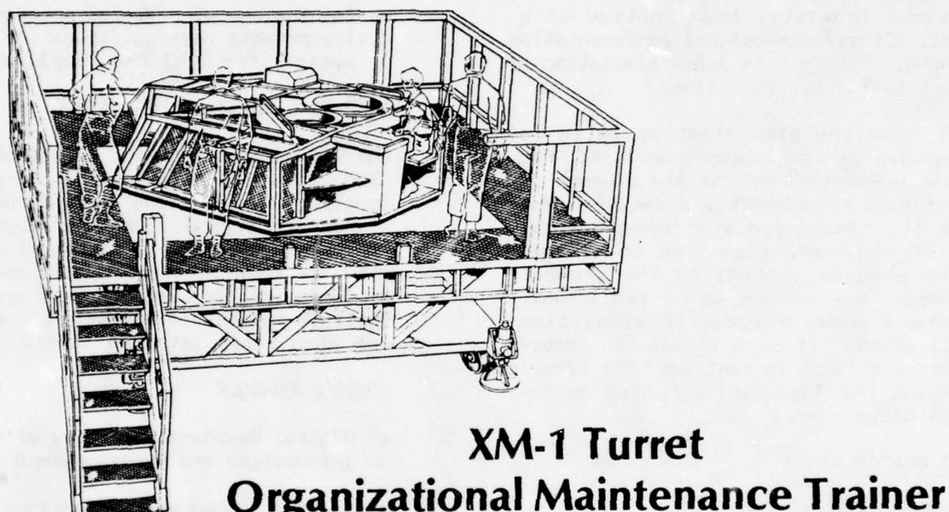


Figure 5.

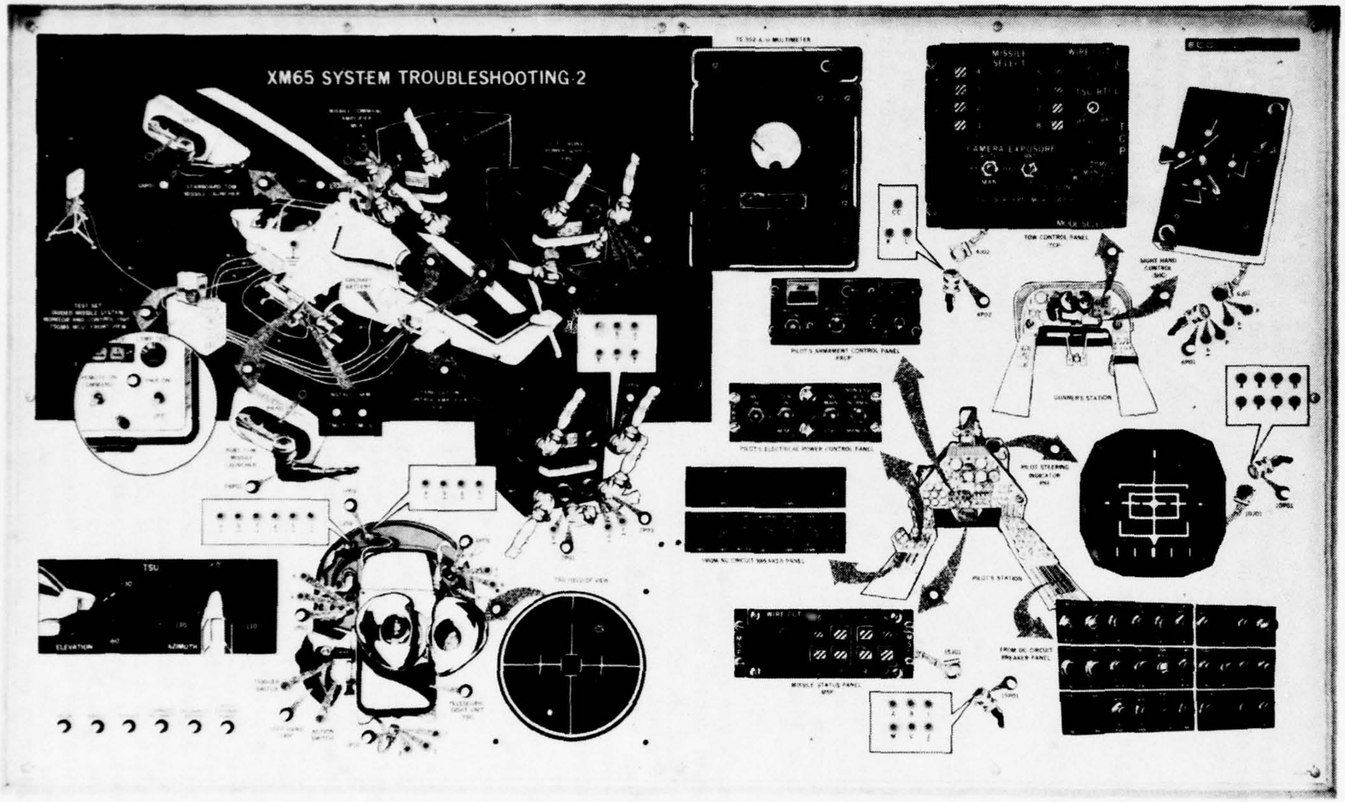


Figure 6. XM65 SYSTEM TROUBLESHOOTING 2

TELETYPE

o ASR 33-35

STORAGE SCOPE DISPLAY

o For use in Graphics Simulation

AUXILIARY PRINTER

o High speed character or line printer for student performance records and program compilation listings

VISUAL PROJECTION

o Single or multiple 35mm Random Access Projectors

RANDOM AUDIO SIMULATION

o As required

INCREASED CAPABILITY AND TRAINING REQUIREMENTS

From the preceding it is obvious the EC 3 has a capability many times that of a non-dedicated system and, at the same time, the basic system hardware is less costly. Our EC 3 is less expensive than the EC II.

The microprocessor has greatly extended the range and detail available in simulation. The EC 3 is not limited to the two-dimensional panel. It can drive just about anything: cockpit procedures trainers, three-dimensional trainers, interface with actual equipment, modular add-on test devices. Even detailed intermediate level maintenance activities can be simulated. The EC 3 can readily simulate electronic component testing using meter or oscilloscope probes.

But all this comes with its price. As everyone should know, the greatest cost in putting a computing system on-line is generated by the software development. The added capability created by the microprocessor is something of a mixed blessing. The hardware procurement cost is going down, but with increased simulation detail and fidelity readily available, the software development, if not controlled, not only makes up the difference, but can become prohibitive. However, this cost can be controlled by accurately prescribing the fidelity requirements.

This is not simply a matter of whether or not to use a 3-D or 2-D simulator, but how much detail in physical and functional fidelity will be necessary to meet the learning objectives. Microprocessor technology isn't making the training technologist's job easier. It is placing greater demands on him. No longer is he conveniently restricted and bound to the confines of the available equipment. He must now sharpen his techniques to be able to accurately specify the training equipment support requirement. It becomes his burden to accurately specify the training and media requirements. Cost effective training simulator design becomes his liability.

It is very easy to retrench and stay within the confines and capability offered by existing off-the-shelf commercial hardware, but that is passing up the opportunity to increase the effectiveness of applicable training.

ABOUT THE AUTHOR

MR. NICHOLAS A. SIECKO *is Vice President of the Educational Research and Development of the Educational Computer Corporation, Orlando, Florida, and directs all of the educational projects for the company. He directed the federally sponsored experimental and demonstration manpower training center (Northeastern Pennsylvania Technical Center). Mr. Siecko is a co-holder of the patent for the design of the company's EC II general-purpose simulator and was responsible for establishing the training concepts which are now being implemented. He established the approach used in the design and development of simulation models used with the EC II, and the instructional programs for the SMART simulator. While with the Systems Operations Support, Inc., he developed, prepared, instructed, and evaluated vocational high school technical courses in one of the earlier attempts to apply a systems approach in a public school district vocational technical high school. He was employed by Burroughs Corporation as a programmer and later as a systems analyst on the Atlas Missile Project. Mr. Siecko is a member of the American Society of Training and Development, National Security Industrial Association, and a charter member of the Society for Applied Learning Technology. He has a B.A. degree in mathematics and has done graduate study in psychology at the Villanova University.*

VISUAL INFORMATION DISPLAY SYSTEM

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US Army Combat Developments Experimentation Command
and
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DBA Systems, Inc.

I. INTRODUCTION

The Visual Information Display System (VIDS), built by DBA Systems, Inc., for the US Army Combat Developments Experimentation Command (CDEC) represents an innovative and flexible approach to the display of field experimentation data. A fundamental aspect of CDEC's experimentation mission is that of two-sided, free-play field exercises in which casualty assessment is carried out in near real-time, with a high level of data collection instrumentation on down to the individual player elements which can be infantrymen, tanks, aircraft, or other weapon systems. The purpose of this form of experimentation is the collection of pertinent data from a realistic battlefield environment.

The primary function of VIDS is the graphical representation of player position and status data which is collected and processed by the CDEC Real-Time Casualty Assessment Instrumentation for use in real-time monitoring and post-trial analysis of experimentation activities. The display is multichromatic, and utilizes pre-programmed symbols to depict various player types. In addition to computational and display equipment, VIDS includes a map digitization system which provides the capability to record and process terrain or other data for background information overlays.

This paper presents an overview of the VIDS and the CDEC Instrumentation to which it is interfaced. It discusses the capabilities and design features which are built into the display system. Finally, other potential uses of VIDS or a VIDS type system are considered.

II. SYSTEM OVERVIEW

The primary instrumentaion system for collection and handling of CDEC's range experimentation data is the Range Measuring System, or RMS. When interfaced to a central computing complex, the RMS provides a position locating capability as well as a two way telemetry link between this central complex and the individual player element. Other instrumentation systems, such as the Direct Fire System, which is a laser based weapons engagement simulation system, or the posture sensor system which allows for the continuous monitoring of player posture, are interfaced to the RMS in order to provide the capability for Real-Time Casualty Assessment (RTCA) in a mock battle experimentation scenario.

The basic concept of the RMS is that the individual player, instrumented with the proper receiver-transmitter and digital logic equipment, responds with a unique code to signals from multiple interrogation stations which are placed at fixed, surveyed locations. The transmission time of these RF signals between a player element and the fixed interrogator stations allows the computation of position location using a multilateration technique. The raw range data are passed via RF link to the RMS control station or C-Station, which is directly interfaced to an on-line real-time multi-computer complex, where the multilateration computations, simulations, RTCA decisions, and system control take place.

The complete RF link from the individual player element via the interrogator station to the C-Station and Multi-computer System can be used as a two way telemetry link in addition to allowing the measurement of position location. Thus, field event data (such as fire events from the Direct Fire System, or the detection of a "hit" from a laser detector responding to the fire event) are passed back to the Multi-computer System, and data such as the results of the casualty assessment (player kill, near miss, mobility kill, etc.) are passed from the computer to the player element.

Figure 1 shows an overview of the data flow from the RMS through the Multi-computer System to VIDS. Within the RMS are player elements (B units), surveyed interrogator stations (A stations) and a control station (C station) which is driven by a local minicomputer. Field data collected by the RMS includes raw range data between player elements and various interrogator stations, as well as telemetry data such as firing events

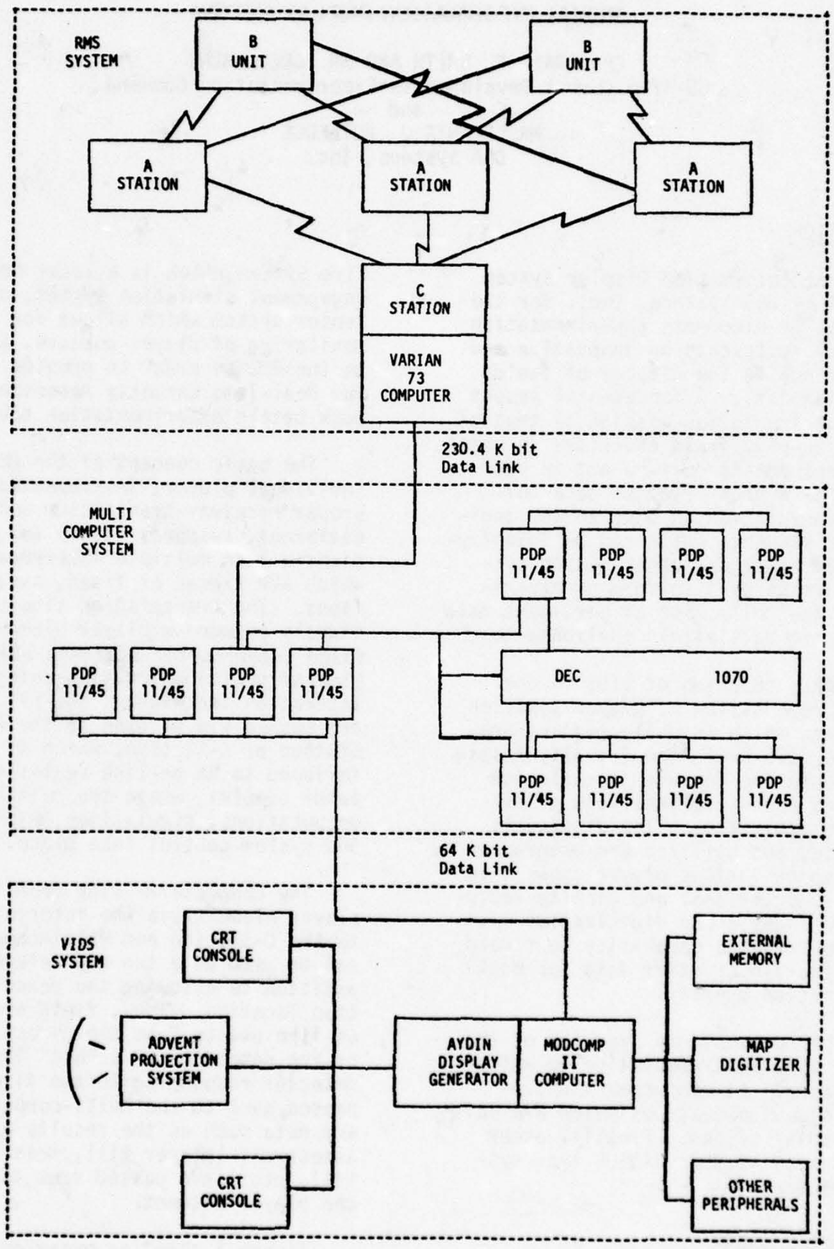

Figure 1
System Overview

from laser weapons simulators, laser hit detection, or other digital data depending on the instrumentation utilized for the particular experiment.

The Multi-computer System communicates with the RMS over a data link. Data is logged and processed at the computer system to allow modeling and simulation of weapons systems, and real-time casualty assessment as a result of events occurring in the field. At the computer center the raw ranging data is processed in near real-time to yield position location in three dimensions as an input to the casualty assessment process.

Finally, VIDS is interfaced via data link to the Multi-computer System. The data handled at the central computer, and therefore available at the interface to VIDS, include player position as a function of time, field event data, and casualty assessment information. The basic design of VIDS permits a high degree of flexibility in the method chosen for the depiction of this basic data. A description of the display design and features will be covered in the following sections of this paper.

III. HARDWARE FEATURES

Figure 2 shows the detailed hardware configuration of the VIDS, which is contained in a 55' by 10' semi-trailer van. The van is EMI protected, thermally insulated, and contains the environmental control and power distribution equipment necessary for system operation.

The data input to VIDS is through a 64 K bit hardwire data link terminated by CODEX 8315 modem adapters.

Standard peripherals to the MODCOMP II Computer include a card reader, printer, dual magnetic tape drives, and fixed (1 MB) and moving head (2.5 MB) disks. The Video Map Converter System, which will be discussed later, is a non-standard peripheral designed specifically for VIDS. The display subsystem consists of an Aydin Image Processing Display Generator, two-high resolution color CRT consoles with keyboards and light pens, and an Advent color projection system with keyboard for a large screen interactive display.

The map digitization or video map converter system permits the recording and processing of terrain or other data for background information overlays. Figure 3 is a block diagram of the map converter system. VIDS has the capability of storing up to 30 map background overlays for any real-time trial. The stored map backgrounds can be activated, translated, and scaled in the real-time or playback display of experimentation data. The pre-mission processing of map data includes map digitization, registration of coordinate locations, correction of rotational distortion, and other map editing as required.

Figures 4 through 7 are photographs showing the VIDS trailer, the map digitization equipment, and the CPU and display areas of the van.

IV. OPERATIONAL FEATURES

As previously discussed, the data which can be displayed on VIDS include player position information for up to 100 player elements, and field event and casualty assessment data which can be displayed through alphanumerics or graphic elements.

Figure 8 shows the VIDS display layout. The active playing area is centered on the screen. This area contains the map background and symbols representing player positions registered to the background coordinates. The operator can request display of all players, or a subset by player type. Path points identifying up to 30 previous positions can be requested for the players. An additional player annotate which consists of up to four alphanumeric characters located in the active playing area adjacent to the player symbol can be called up for the players.

The operator has the capability of selecting from up to 30 different map backgrounds. Display maps can be translated, blown-up to two, four, or eight times normal, or a completely different map may be displayed.

The upper right hand area of the display contains the range and elapsed times, and codes identifying the mode of operation and playback rate which is selectable by keyboard command from one tenth to five times real-time speed.

Along the right edge of the display are the control and menu areas. The control area permits the operator, through his light pen or keyboard cursor, to activate player detail data displays and map translation and scaling commands. The menus allow selection of any combination of up to 30 menu overlays which contain static or dynamic graphic element data. As an example, a menu could contain information concerning direct fire events which might be depicted as a flashing straight line connecting the involved players for a predetermined period of time.

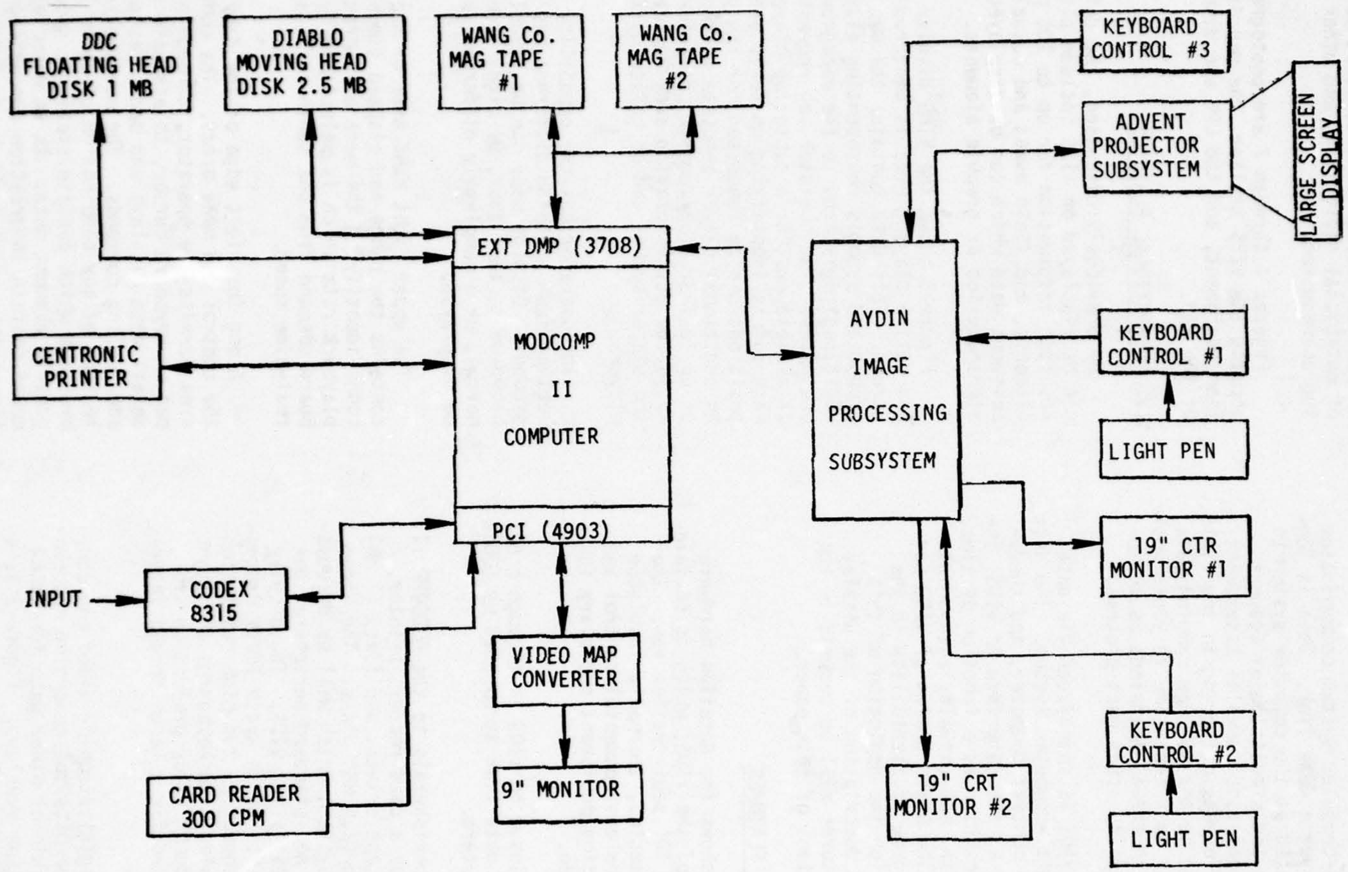

Figure 2

Visual Information Display System Block Diagram

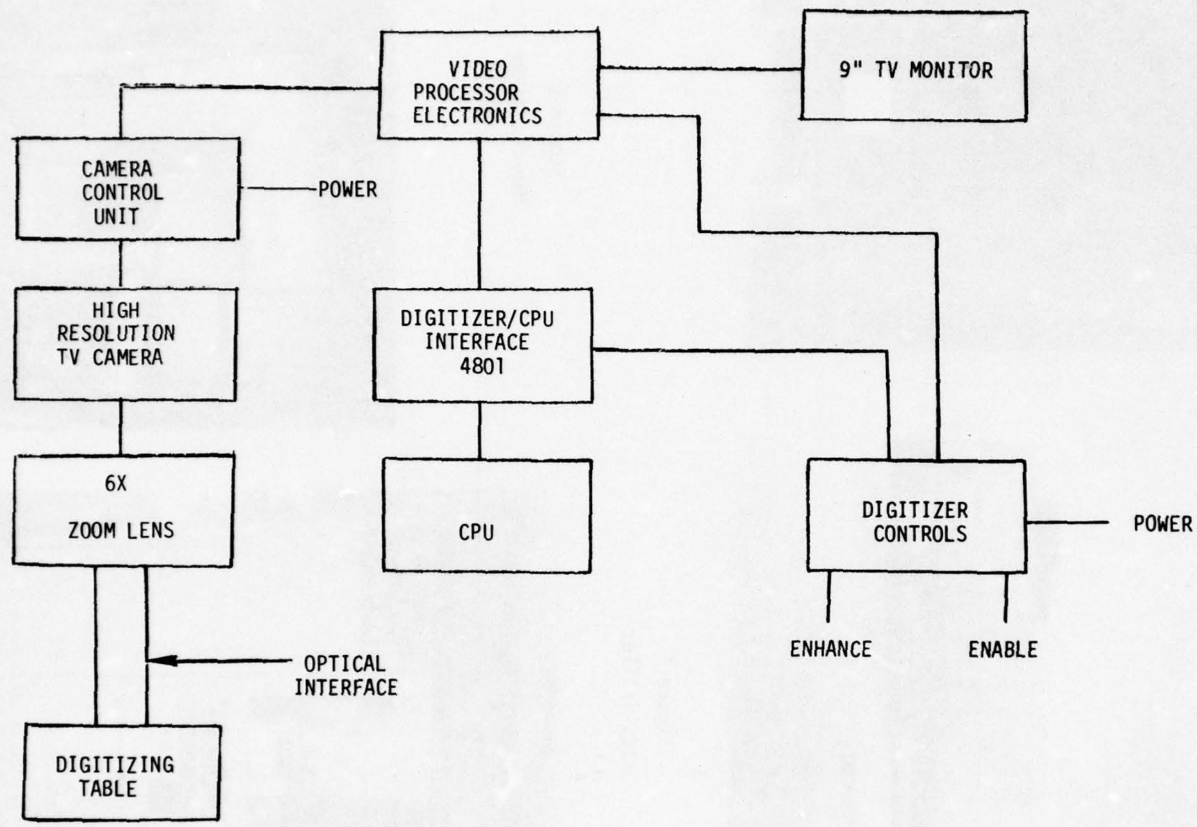

FIGURE 3

Map Converter Block Diagram

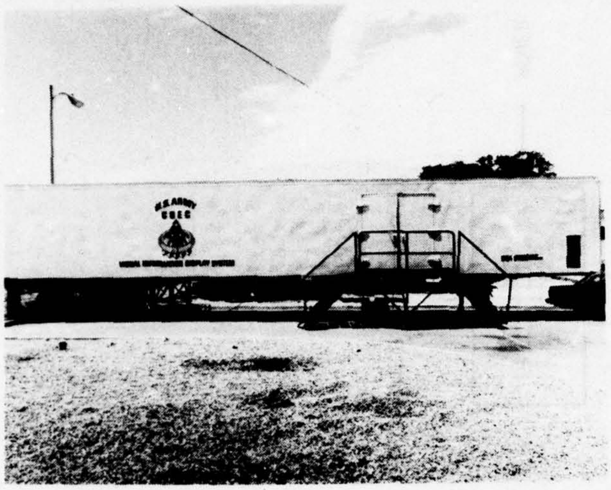

Figure 4
VIDS Trailer

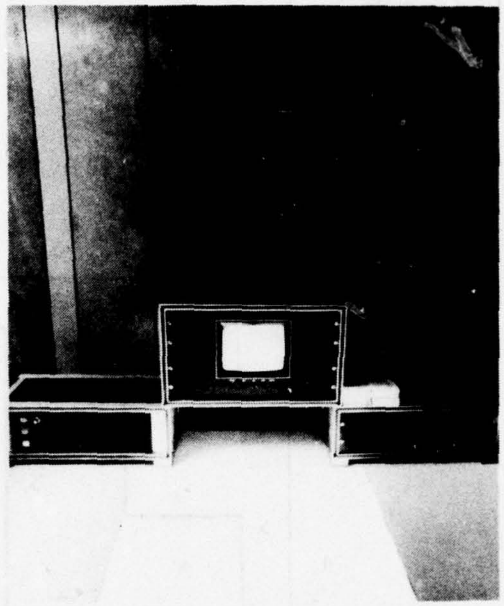

Figure 5
Map Digitizer

Figure 6
CPU Area

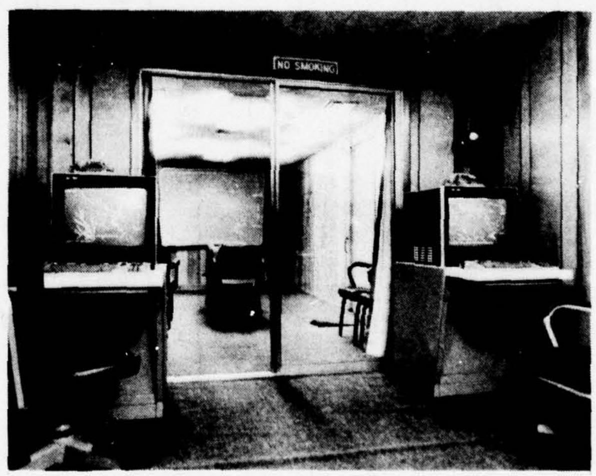

Figure 7
Display Area

Figure 8
VIDS Display Layout

The left margin of the display contains detail data concerning individual players which can be selected from the keyboard or the cursor/light pen system. Information such as X, Y, Z coordinates, number of rounds of ammunition remaining, and time of last direct fire event could be included in this area.

Finally, the upper edge of the display contains space for header messages, and the lower edge contains space for footnote information to include operator communications messages within the VIDS system or between VIDS and the host computer system.

The three interactive consoles are independent of one another with the exception that playback rate, selectable at any console, applies to all displays.

V. SYSTEM UTILIZATION

The primary intended uses for VIDS include monitoring of field experiment data in real-time and enhancement of the post-trial analysis of experimentation results.

The real-time activities permit quality control during the trials with the potential to allow trials to be stopped, continued, or re-run as necessary depending on the quality of the data being collected. In the past, invalid experimentation trials have been due to instrumentation failures on key players which were not detected until the data was reduced. The quick look quality control capability can be used to avoid this costly form of experiment invalidation.

Used as a tool in conjunction with instrumentation checkout and initialization, VIDS is expected to reduce the time requirements for countdown and fault analysis, thereby reducing costs and increasing the potential number of trials per day.

The system can provide the experiment proponent and CDEC planners and controllers with an immediate and comprehensive understanding of the complex relationship between players, instrumentation, and equipment.

In its use as a tool in the post-trial analysis of experiment data, VIDS places the pertinent information at the finger tips of the analyst through visual graphics as well as alphanumeric displays. This represents a significant enhancement of the data reduction capabilities which previously were restricted to CRT and hard copy alphanumeric printouts. Additional analysis enhancements include slow motion - fast motion playback capability, map translation and scaling to change perspective, and menu selection to correlate trial activities with other data of importance.

The flexibility in depiction of display information which was designated into VIDS permits a wide range of additional potential uses for the system, primarily in the area of a command and control display. Some of these alternative uses include command and control for experimentation activities and training operations.

The logical first expansion of the capabilities of VIDS would be in going from a pure test data monitor and analysis system to an active command and control center for experimentation operations. The primary system upgrades which would be required to provide for this enhancement are increased radio communications, additional display monitor stations, and possibly an improved large screen display capability.

In the area of training operations, a VIDS type system can be envisioned as being used in the monitoring of large scale training operations, and in the post-operational de-briefing stage of the training exercise. The training operation would require data collection instrumentation in addition to the display system and host computer.

The training exercise being monitored could be of the form of a National Training Center type operation, or the training mission of tactical field units at their normal field training sites. In addition, such a system could be visualized as being used in conjunction with large scale joint service field exercises to provide important information concerning key personnel in the operation.

The slow motion - fast motion capability of the system, as well as the capability to portray information against selected background data make a system such as VIDS an effective debriefing tool in the post-operational phase of the training exercise. In addition, the on-board computer may provide the capability for data reduction and post-operation tabulation of results. This could be used as an effective tool in the utilization of the training exercise results to guide the unit or key personnel in improving its level of performance in the future.

In summary, the flexibility of the design of VIDS and its unique map digitization system provide CDEC with an improved experimentation monitor and analysis capability, and these same features will allow for future expanded uses within CDEC or alternative uses for a similar system elsewhere in the military community.

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COMPUTER GENERATION OF FULL COLORED TEXTURED TERRAIN IMAGES

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1. INTRODUCTION

Computer generated shaded relief maps have been used in cartography for a number of years. Most systems produce gray level images which are simple orthographic projections of the terrain surface. We will show how digital terrain data can be used to create more realistic displays.

2. U.S. DEFENSE MAPPING AGENCY DATA

The U.S. Defense Mapping Agency (DMA) has assembled digital map data for certain areas of the Earth. Their source material includes aerial photographs, topographic charts, remotely sensed imagery, and ground truth information. DMA data is intended for such applications as static map generation, radar land mass simulation, flight simulation, and cockpit displays for high speed low flying aircraft.

The DMA supplies two categories of data [1]: terrain and "culture" files. A terrain file is an array of elevation values for a region of the Earth. The sampling interval of the terrain is a function of latitude (Table 1). The elevation array for each terrain region is stored on magnetic tape at two different resolutions.

Table 1. DMA Terrain Data Intervals

	Level 1	Level 2
Latitude	Lat. X Lon.	Lat. X Lon.
0°-50°N-S	3 x 3 Seconds	1 X 1 Second
50°-70°N-S	3 X 6 Seconds	1 X 2 Seconds
70°-75°N-S	3 X 9 Seconds	1 X 3 Seconds
75°-80°N-S	3 X 12 Seconds	1 X 4 Seconds
80°-90°N-S	3 X 18 Seconds	1 X 6 Seconds

A culture file holds the descriptions of man-made and ecological surface features within a given terrain region. Most feature types are represented by a polygonal boundary and a coded description. However, the locations of some features such as bridges, dams, walls, and pipelines are given as polygonal lines, while others such as tall buildings and water towers are given as points.

Culture polygons are assigned both a predominant surface material and a more specific surface description. The 13 general categories of surface materials are given in Table 2. As an example, the general category assigned to a culture polygon may be "trees". The particular subclasses under this heading are orchard, deciduous forest, coniferous forest, evergreen, and mixed forest. Each tract of trees is given a predominant tree height.

3. EQUATIONS FOR DISPLAYING A SHADED RELIEF MAP

Suppose that a terrain surface $H(x,y)$ is illuminated by both direct sunlight and ambient light. The location of the sun is given in terms of its azimuth θ and elevation ϕ. Azimuth is measured clockwise from North,

Table 2. Thirteen DMA Predominant Material Types

1.	Metal
2.	Part Metal
3.	Stone/Brick
4.	Composition
5.	Earthen Works
6.	Water
7.	Desert/Sand
8.	Rock
9.	Asphalt/Concrete
10.	Soil
11.	Marsh
12.	Trees
13.	Snow/Ice

while elevation is the angle between the sun and the horizon (Figure 1).

Let P_λ denote the quantity of (direct) sunlight reaching the terrain surface. Under a simple model, the amount of sunlight reflected by a surface element is related to the cosine of the incident angle i. Let $\vec{n}(x,y)$ denote the unit normal at a surface element (x,y) and $\vec{n}_p$ be a unit vector in the direction of the sun (Figure 2). Then

$$P_\lambda \cos i = P_\lambda[\vec{n}(x,y) \cdot \vec{n}_p]$$

where

$$\vec{n} = \left[\frac{-\partial H(x,y)}{C\, \partial x}, \frac{-\partial H(x,y)}{C\, \partial y}, 1/c \right],$$

$$c = \left[1 + \left(\frac{\partial H(x,y)}{\partial x}\right)^2 + \left(\frac{\partial H(x,y)}{\partial y}\right)^2 \right]^{1/2}$$

and

$$\vec{n}_p = [\sin\theta \cos\phi, \cos\theta \cos\phi, \sin\phi].$$

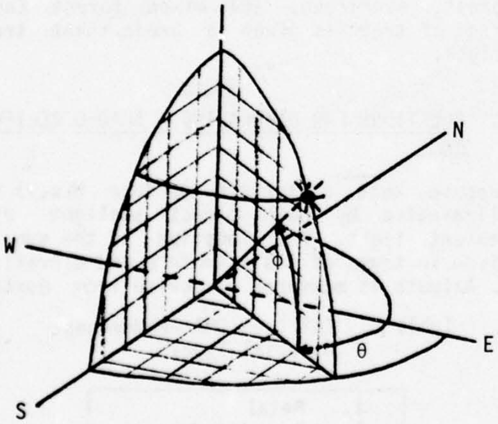

Figure 1. ϕ = Angular Elevation of the Sun; θ = Sun Azimuth

We will also assume that the surface is illuminated by ambient light. Ambient light strikes a surface equally from all directions and is assumed to be reflected equally in all directions. The intensity of ambient light for wavelength λ will be denoted by A_λ.

The albedo of an object is the fraction of the incident energy which is reflected by the object over the entire electromagnetic bandwidth. The albedo of a surface for frequency λ will be denoted by r_λ. It is the fraction of the energy of that wavelength which is reflected. Tables exist for r_λ for many materials [2-6]. The visual albedo of an

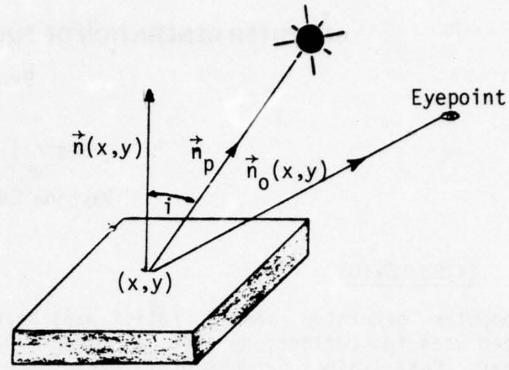

Figure 2. Unit Direction Vectors

object refers to the object's albedo as perceived by the human visual system. It is the product of the object's albedo and the spectral luminosity of the human eye.

A number of simplifying assumptions are needed before we can present an equation for the appearance of a surface. We will assume that reflected light from one surface element does not illuminate another surface element. This effect is difficult to model and will lead to global computations.

We will assume that surface elements do not cast shadows on each other. This restriction can be lifted by using one of the shadow algorithms given in the computer graphics literature.

Computer generated images are usually displayed on cathode-ray tubes (CRT's). Our equations do not include compensating terms for the spatial nonlinearities of a CRT or its emmission characteristics. Good discussions of these problems can be found in [7] and [8].

Under the above assumptions, the appearance of surface element (x,y) over the visual bandwidth is given by$\{R_\lambda(x,y)/380 \text{ nm} < \lambda < 770 \text{ nm}\}$, where

$$R_\lambda(x,y) = P_\lambda \max\{0, \vec{n}(x,y) \cdot \vec{n}_p\} \cdot r_\lambda(x,y) + A_\lambda r_\lambda(x,y).$$

Before an image is displayed on a color cathode-ray tube, frequency values are usually converted first to CIE tristimulus values and then to red, green, and blue intensity levels. These transformations are described in detail in [7] and [8]. The color image R(x,y) may be called the <u>reflectance map</u> of the field.

An example of a DMA terrain file is shown in Figure 3a. Here, high gray levels are used to represent high elevation values. The corresponding culture map is given in Figure 3b. A "sun-shaded" overhead view of terrain with culture is displayed in Figure 3c. A perspective projection of the scene is shown in Figure 3d. It was created by using the algorithm given in the Appendix.

4. ADDING TEXTURE TO A SCENE

When we view a terrestrial landscape from the air, we see a mosaic of different plant species and land uses. Expensive agricultural machinery forces farmers to plant their crops in large rectangular fields. Cities, forests, swamps, oceans, and deserts all have distinctive appearances. The individual characters of some of these surface features are due mainly to their color. However, others are distinguished by both color and texture. We may sample aerial photographs to obtain prototype textures. The area scanned should be flat, fairly homogenous, and free of ecological anomolies.

These prototype patterns will be put onto a terrain surface in the following manner.

First, we use DMA elevation data to create an overhead view of a shaded relief map. Then we identify a polygonal region on the map which is to receive a particular texture. The appropriate texture prototype is then used to modulate the color intensity of this region.

It should be understood that this process involves an inherent distortion of the texture array, since we are projecting a planar pattern onto a three-dimensional surface. Also, the sun angle and elevation of the texture prototype may not correspond to that of the image which we are creating. Nevertheless, texture very effectively adds to the realism of a scene.

Figure 4a shows a prototype forest texture, Figure 4b was produced by modulating the color within forest regions of Figure 3c. A perspective projection is shown in Figure 4c.

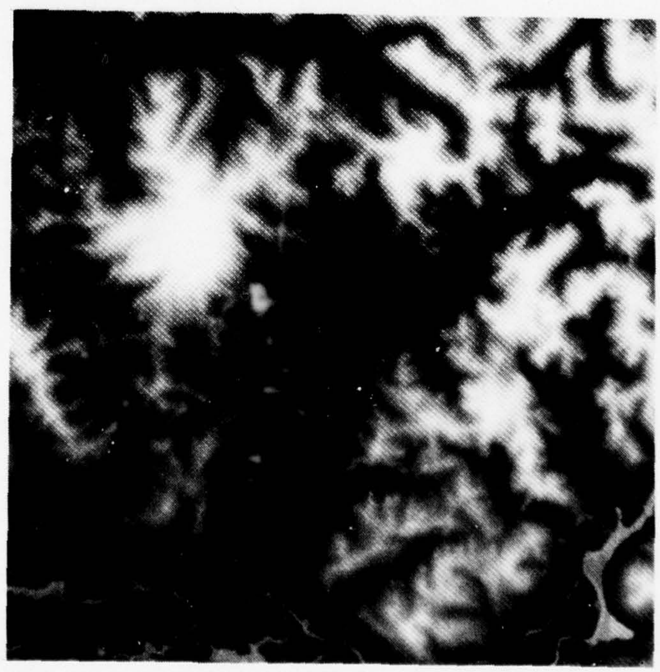

Figure 3a. Terrain Map, High Gray Levels Represent High Elevation Values

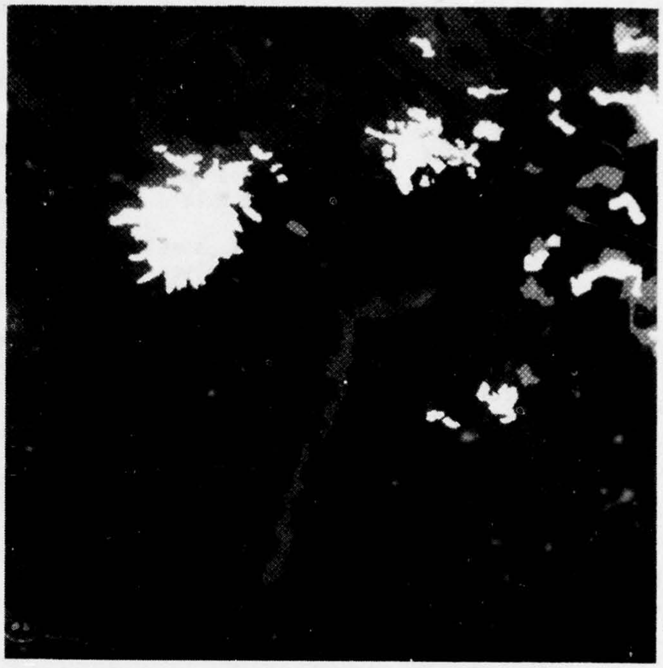

Figure 3b. Culture Map, [Note: All Photographs Are Black and White Version of Original Color Photographs]

Figure 3c. Sun-Shaded Terrain with Culture

Figure 3d. Terrain with Culture, In Perspective

Figure 4a. Texture Array (Deciduous Forest)

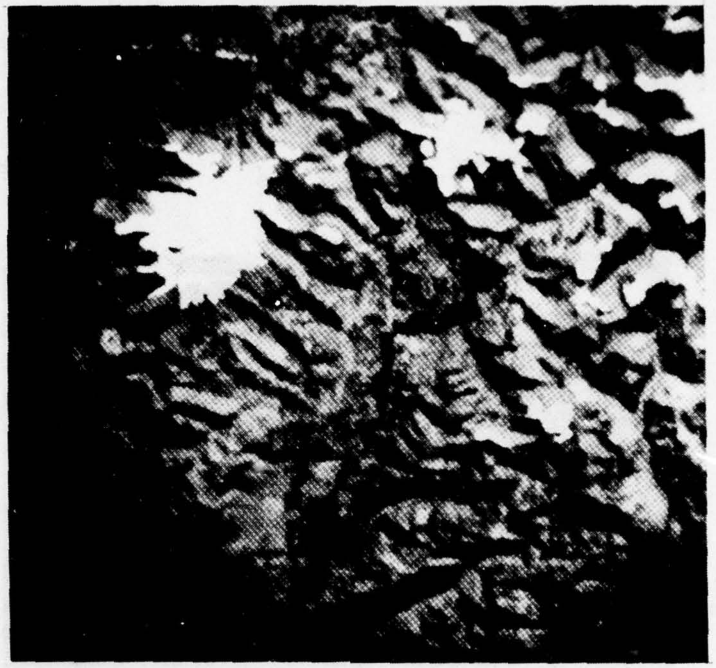

Figure 4b. Terrain with Culture and Texture

Figure 4c. Terrain with Culture and Texture, In Perspective

References

1. ---, Product Specifications for Digital Landmass Systems Data Base, Defense Mapping Agency, St. Louis AFS, Missouri, July, 1977.

2. C.D. Hendley and S. Hect, The Colors of Natural Terrain and Their Relation to Visual Color Deficiencies, J. Opt. Soc. Am. 39(10), 1949, 870-873.

3. E.L. Krinov, Spektral'naia Otrazhatel'nia Sposbnost' Prirodynykh Obrazovanii (Special Reflectance Properties of Natural Formations), Lab. Aerometodov, Akad, Nauk SSSP, Moscow, 1947.

4. D. Nickerson, K.L. Kelly, and K.F. Stultz, Colors of Soils, J. Opt. Soc. Am., 297-300, 1945.

5. R.L. Rendleton and D. Nickerson, Soil Colors and Special Munsell Color Charts, Soil Science 71, 1951, 35-43.

6. R. Penndorff, Luminous and Spectral Reflectances as Well as Colors of Natural Objects, Air Force Cambridge Research Center, Bedford, Mass., Geographical Research Paper 44, 9ASTIZ No. AD-98766, AFCRS-TR-56-203), 1956.

7. R.F. Ferreland and J.M. Booth, Design Handbook for Imagery Interpretation Equipment, Boeing Aerospace, Seattle, Washington, 1975.

8. A.P. Verdi, Reproduction of Color in Computer Image Generation Displays, General Electric Tech. Pubs, Daytona Beach, Florida, 1979. (Not available for distribution.)

9. B.J. Schachter and B. Fishman, Computer Display of Height Fields, General Electric Tech. Pubs, Daytona Beach, Florida, 1979.

APPENDIX

ALGORITHM FOR VIEWING A HEIGHT FIELD IN PERSPECTIVE

Provide the following parameters. Typical values are shown in parenthesis.

FOV	=	field of view (0.6)
VSC	=	vertical scaling constant (0.3)
DOF	=	depth of field (1000)
ALPHA	=	view angle counter-clockwise from x-axis ($\pi/2$)
V	=	VX, VY, VZ = viewpoint (256,0,200)
IH	=	line number of horizon
H(X,Y)	=	height field
R(X,Y)	=	reflectance map

Note: A screen size of 512-by-512 is assumed.

```
    DO LINE = 0,511
       DO I = 1,512
       BUFF(I) = sky-color
       END DO
    TANG = (LINE-256)*FOV/256.
    GAMMA = ARCTAN(TANG)
    DX = COS(ALPHA-GAMMA); DY = SIN(ALPHA-
                                  GAMMA)
    MCOL = 0.
    RANGE = 0.
    Y = VY; X = VX
 A: IF(RANGE .GT. DOF .OR. MCOL .GT. 511) GO
    TO C
    T = VSC*H(X,Y) - VZ
       IF (RANGE .LT. .01)
       TANB = SIGN(0.3*FOV,T)
       ELSE
       TANB = T/RANGE
       END IF
    ICOL = MIN{(512-IH)+TANB*256./FOV,511}
       IF (ICOL .LT. MCOL) GO TO B
       IF (MCOL .EQ. 0) MCOL = ICOL
       DO K = MCOL,ICOL
       BUF(K) = R(X,Y)
       END DO
    MCOL = ICOL + 1
 B: X = X + DX; Y = Y + DY
    RANGE = RANGE + COS(GAMMA)
    GO TO A
 C: Scan BUF out on crt LINE
    END DO
```


Acknowledgement: The author would like to extend his appreciation to Barry Fishman for his assistance in the preparation of this paper.

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ADVANCED FEATURES IN CONTROL LOADING AND MOTION SYSTEMS FOR SIMULATORS

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Thomson-CSF Simulateurs LMT-France

INTRODUCTION

The ideal simulator would be a device in which a pilot could feel he was effectively in a real vehicle and which would also be easy to operate, easy to maintain and cost little. Although these characteristics are somewhat conflicting, there are reasonable solutions which provide a fair compromise. This paper describes the solutions adopted by Thomson-CSF Simulateurs LMT for motion systems and control loading systems in particular.

MOTION SYSTEMS

Depending on whether it is within the pilot loop or outside it, the motion system can be said to fulfill two roles. In its role outside the pilot loop, the motion system provides essentially disturbing effects such as the simulation of turbulence in an aircraft or the simulation of ground irregularities in a ground vehicle. This role does not require a high degree of performance from the motion system, for it is simply necessary that the source of the effect be identifiable. In its role within the pilot loop, on the other hand, one expects the motion system to maintain the gain and phase of pilot inputs at the level they are in the aircraft. To attain this objective, the motion system must, of course, possess a wide bandwidth and a large excursion, but primarily it must not introduce effects which could cause negative transfer of training such as the reversal bump which occurs in many motion systems when the platform slows down, stops and changes direction of motion. The importance of smoothness of motion is now recognized by many users and workers are investigating these problems [1] to identify the main parameters and to develop methods of measurement.

The solutions we have employed in our advanced 6 DOF motion system (figure 1) respond to these new requirements.

Smoothness of motion

Smoothness of motion is gauged by the level of acceleration noise. In motion systems, acceleration noise appears principally during direction reversals in the form of bumps due to coulomb friction in the jack and to servo valve non linearities. In conventional jacks the main sources of coulomb friction are the high-pressure seals between piston and cylinder and between piston rod and cylinder. These high-pressure seals have been eliminated by the use of hydrostatic bearings and both the piston and the piston rod are supported on a thin film of oil. The principle of hydrostatic jack bearings is illustrated in figure 2. The rod is supported by a tapered hydrostatic head bearing and piston. The bearing and piston centering force is proportional to the difference between the pressure applied on either side of the tapered section (the higher pressure is on the side with the smaller piston diameter). The piston and piston rod are mechanically isolated from the cylinder and head bearing by a thin film of oil, due to leakage through the tapered sections. Because of its unfavorable influence on acceleration noise during direction changes, it is important to minimize this leakage which can be done by using operating clearances [2] of the order of 0.05 mm (0.002 in) to 0.08 mm (0.003 in). Since the piston now creates very little friction, that which remains is due entirely to the low-pressure seal for head bearing leak recovery. And, because the low-pressure seal represents less than 10 % of the friction of the high-pressure seals used in conventional jacks to provide the head bearing and piston seals, it is immediately apparent that a major increase in performance can be gained using this technique.

The application of this principle to the advanced 6 DOF motion system has resulted in the adoption of double taper hydrostatic bearings for the head bearing and the piston (see figure 3).

Hydrostatic bearing jack. The supply pressure feed to the head bearing maintains bearing centering even when the pressure in the re-entry chamber falls to zero or is increasing to operating pressure. Piston centering is achieved by the pressure difference between the chambers and the return line. Because of the payload, the pressure can never be zero in both chambers at the same time, and piston centering is therefore always ensured. Leakage from the piston and the head bearing are directly re-injected into the return circuit. Coulomb friction for the jack is less than 5 daN (11 lbs) which is due entirely to the low-pressure seal friction.

Servovalve. Acceleration noise due to jack friction is practically eliminated by the use of hydrostatic bearings but noise due to the servovalve still remains; stringent servovalve specifications provide a solution to

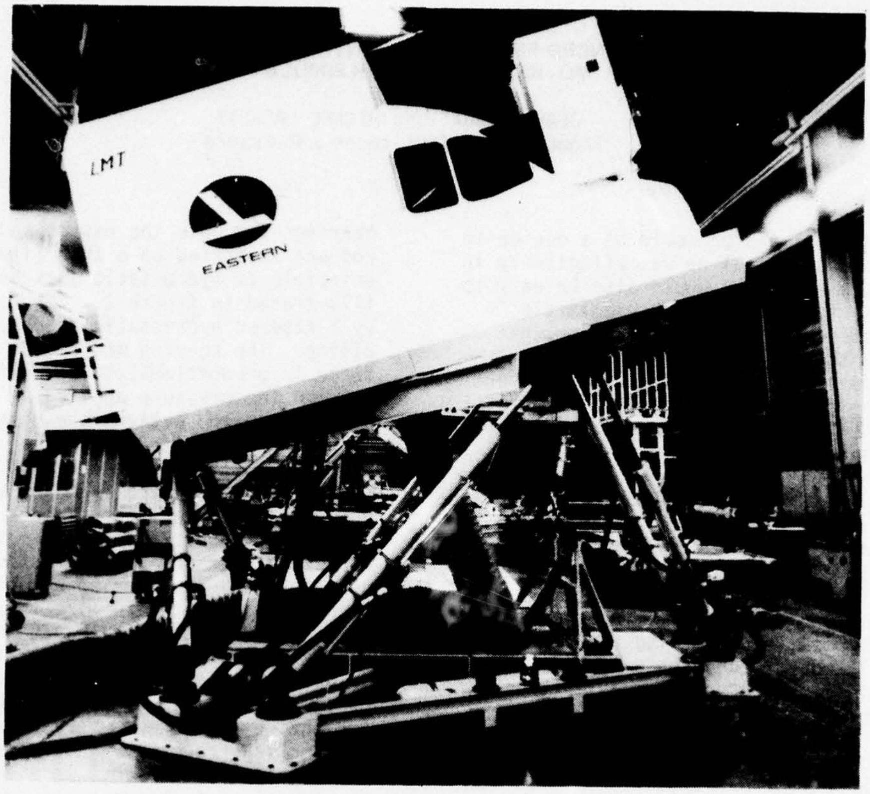

Figure 1 - Advanced 6 DOF motion system

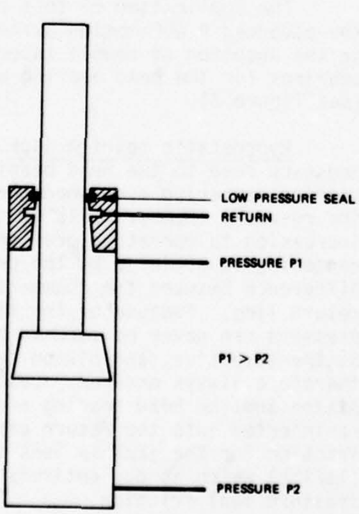

Figure 2
Hydrostatic jack principle of operation

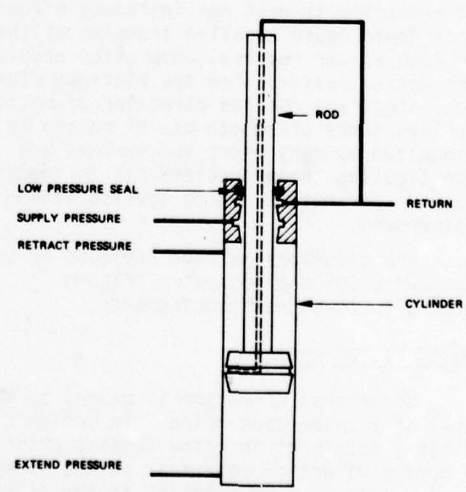

Figure 3
Advanced 6 DOF motion system hydrostatic jack

this problem. The main parameters concerned are :

- Flow linearity through the neutral position
- Hysteresis
- Resolution.
- High Speed digital computer.

Although the hydrostatic bearing has a beneficial effect on coulomb friction, its low self-damping must be compensated in the servo loop. The optimum damping ratio of 0.7 is achieved by pressure feedback. Acceleration noise is less than 0.015 g measured for vertical platform motion with an input signal of 10 % maximum drive at a frequency of 0.5 Hz.

Pass band

Although low frequency motion is perceived mainly through visual cues, the higher frequencies are sensed through vestibular cues. It is therefore important that the motion system has a good pass band to maintain the gain and phase of pilot inputs at the levels they have in the aircraft. The bandwidth of the advanced 6 DOF motion system is a function of the servo jack characteristics and of the drive signal which incorporates a phase advance term. See figure 4.

Safety

The mechanical strength of the motion system, clearly an essential element, is the result of a computer-aided design involving resonance, deformation and stress of all parts. Another important safety factor for personnel and material is the limitation of accelerations generated near end of travel to acceptable values in the event of failure of the drive circuits. Integral dampers, fully fail- safe in that they have no moving parts, provide progressive deceleration of the jack at end of travel. A further important point for personnel safety is that the crew compartment has to return to a fully lowered, horizontal position if electrical or hydraulic power should fail. This is achieved by careful mechanical design and by specific safety circuits.

Operating and maintenance facilities

The choice of a 6 DOF synergistic platform motion system improves standardization of parts and therefore facilitates maintenance. The design for simplicity of operation has resulted in the pivots being mounted laterally on the platform, thus reducing its height in the rest position and improving access to the crew compartment and to the equipment bays. The pivots are all identical and run in tapered roller bearings and needle bearings which require lubrication at infrequent intervals and have a long life.

The use of hydrostatic jacks with their negligible rate of wear (there is no contact between the jack rod and the cylinder) and the absence of high-pressure seals has facilitated maintenance. A single low-pressure seal is necessary for head bearing leakage recovery and this seal is easily replaceable without internal disassembly of the jack.

Maintainability of the motion system is also greatly facilitated by the memorization and display of all shut down conditions and by a simulation circuit which dynamically monitors the jack servo loop. This circuit is the subject of a patent application.

CONTROL LOADING SYSTEMS

The pilot's hand is a sensitive and exacting force transducer, not only around the stick neutral position which is the usual flight position, but also over the entire travel of the control column. It is thus particularly important to reduce any drift which could deform the force/excursion relationship and any noise which could impair realism. The control loading system combines the smoothness of low friction hydraulic servo-jacks (figure 5) with the stability of a high-speed digital computer.

Performance

In its function as a force transducer, the human hand has a high sensitivity and a wide bandwidth. It is therefore important that all extraneous noise be excluded from the system. The control loading system must be perfectly stable (no oscillations) and the jack motion very smooth, which implies low friction. It is also important that rapid changes in the stiffness of the aircraft control kinematics be correctly reproduced. This implies a wide bandwidth. The human hand is also sensitive to drift in the force/control surface excursion relationship. The use of a high-speed digital computer considerably improves stability. Possible drift in the analog servo circuits is partly compensated by the digital computer which performs the dual function of command signal computation and command execution monitoring.

Description (see figure 6)

Principle. The kinematics of the aircraft flight controls are entirely simulated by a mathematical model which is a system of second degree differential equations. The resolution of this differential equation system gives the control column loading as a function of the column position. Calculation of the control column loading involves the following parameters:

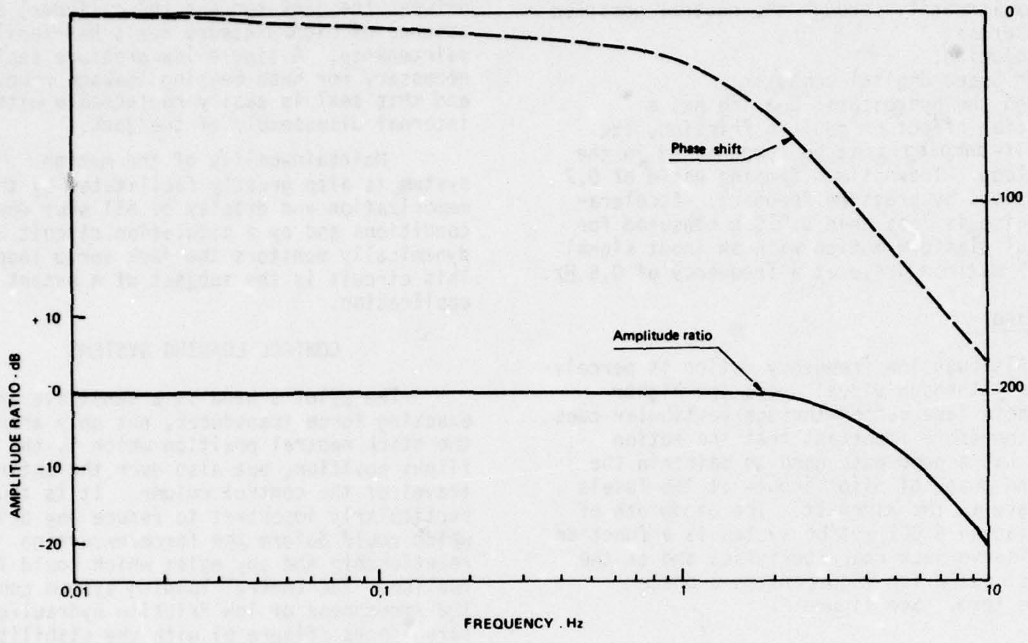

Figure 4 - Frequency response of the advanced 6 DOF motion system

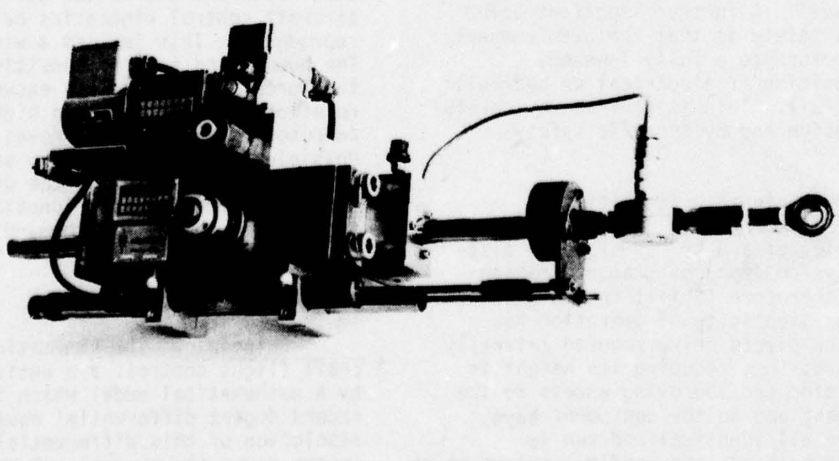

Figure 5 - Control loading jack

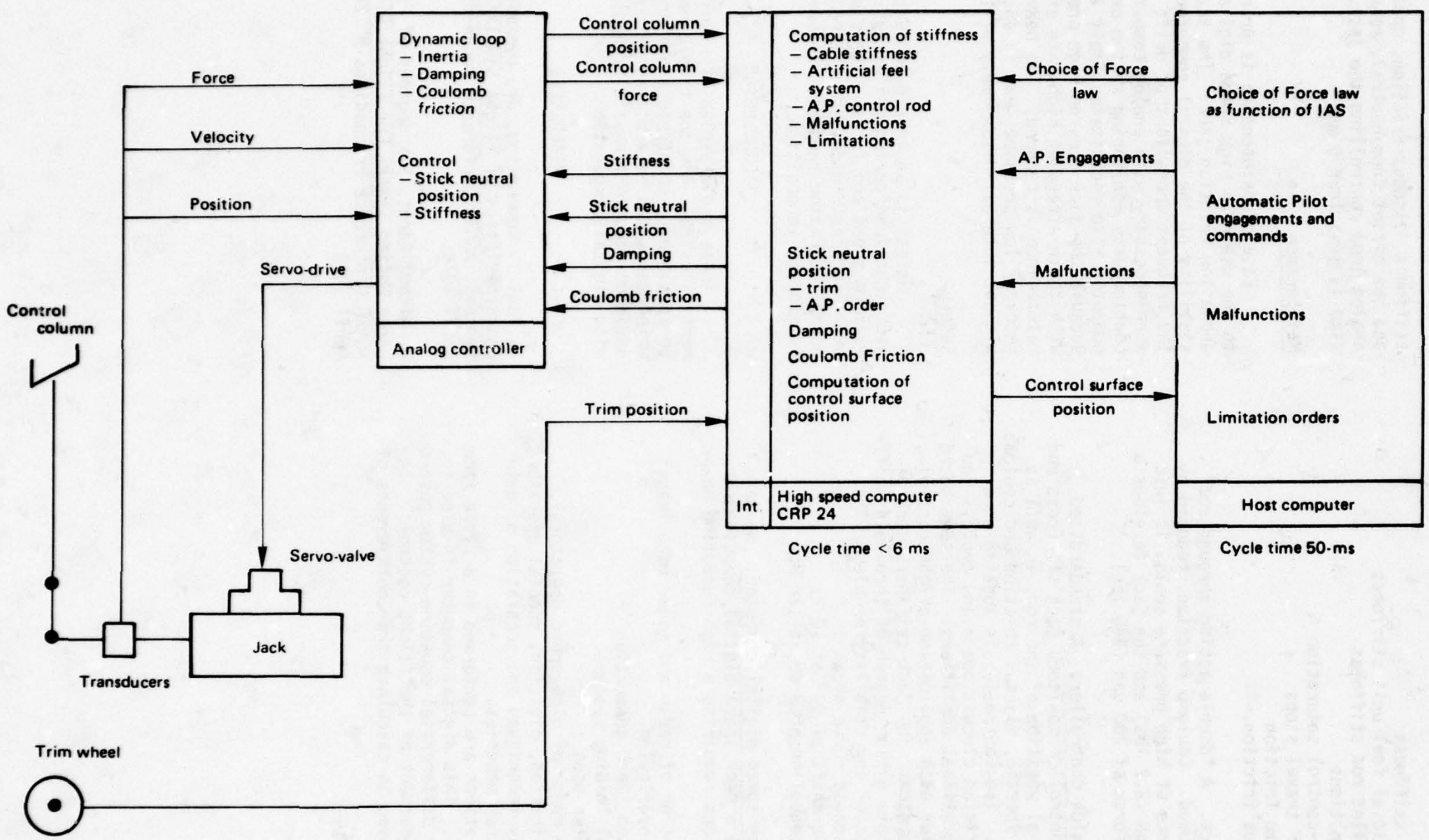

Figure 6 - Control Loading System

- Cable stiffness
- Artificial feel unit stiffness
- Autopilot rod stiffness
- Malfunctions
- Servo-control saturation
- End of travel stops
- Coulomb friction
- Viscous friction.

Jack. A "double acting through rod" jack is used. Coulomb friction, reduced by the absence of high pressure seals, is less than 1 daN (2.2 lbs) and the jack develops a nominal force of 200 daN (440 lbs).

Analog controller. A standardized analog controller monitors jack stiffness and the neutral position of the rod, as well as the jack inertia, viscous friction and coulomb friction. The controller is located on a single printed circuit board and employs low drift operational amplifiers. The same board is used for each application of the control loading system. The jack stiffness control can simulate a high degree of threshold stiffness, without any stability problem. The force response curve shows :
- a phase shift of 90° at 70 Hz
- an attenuation of 3 db at 110 Hz.

High speed digital computer. We have developed a high speed digital computer for applications requiring a high computing power, such as :
- Simulation of radar and sonar echo images
- Image overlaying
- Computed image generation
- Control loading systems.

The computer uses :
- A wide range of high-speed operators (multiplication, division, special operators)
- Overlay techniques and separation of data and program memories.

Most operations are performed in a cycle time of 330 ns. This digital computer is used to solve the differential equation system governing the movement of the flight controls. It is also used to calculate the coefficients of stiffness, viscous friction, coulomb friction and the offset from neutral, required for the analog loop controlling the jack. The cycle time is less than 6 ms.

Maintenance

Ease of maintenance is principally due to the use of a high speed digital computer and a low friction jack. The accuracy and stability of the digital computer eliminate the frequent operations of drift zeroing which were necessary with analog computers. By continuously monitoring system operation, the computer also facilitates fault location. Because the jack uses no high pressure seals with their attendant high rate of wear, jack maintenance is reduced. The bearing leakage recovery low pressure seal is easily removable without internal disassembly of the jack.

Safety

Safety is an intrinsic feature of the jack, obtained during design by limiting maximum speed and force. These parameters are also electronically monitored and, if the normal operating range is exceeded, the jack is stopped in position.

CONCLUSION

These two examples of simulation equipment illustrate how the triple requirement of performance, ease of operation and ease of maintenance can be achieved by combining advanced electrohydraulic technology with digital computation.

REFERENCES

1. Paul T. Kemmerling, Jr, Dynamic Characteristics of Flight Simulator Motion Systems, AGARD Conference Proceedings N° 249 April 1978.

2. Michel Baret, Six degrees of Freedom Large Motion System For Flight Simulators, AGARD Conference Proceedings N° 249 April 1978.

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EMULATION AS A SONAR TRAINER MODEL VALIDATION AND VERIFICATION TOOL

BRUCE R. WALKER
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INTRODUCTION

The development plan for the design and delivery of the Fleet Ballistic Missile Sonar Operational Trainer (FBM SOT) real-time operational computer program included the verification of the mathematical models and their hierarchical structure. Verification was accomplished by the development and utilization of an emulator, a nonreal-time computer program written in Fortran. This emulator was used to: 1) verify the model algorithms and associated logic, 2) verify program architecture, and 3) provide test case data for checkout of the real-time operational program (RTP). The emulator was also intended to serve as a test bed for future real-world data base improvements, and is provided as part of the deliverable SOT system.

This paper describes the conception, development, and use of the emulator as a mathematical model development, validation, and verification tool. Detailed design information is presented elsewhere.[1]

EMULATOR CONCEPT

The FBM SOT emulator can be considered a simulation of the real-time SOT data processing system since it uses the same algorithms and the same computational equipment as the real-time program. The design philosophy for the emulator was to use a main routine that sequentially calls an ordered set of models for processing during each time step. The emulator handles two targets at once, instead of the six simultaneous targets of the FBM SOT. This was considered to be sufficient for design verification of the math models. Computer running time was not considered as a criterion for operation of the emulator; however, reasonable computational efficiency was maintained within the inherent capabilities of the Honeywell H716 system.

The emulator is programmed to operate on the H716 computer used in the FBM SOT system. It makes use of a card reader, disc drive, line printer, and magnetic tape drive with TTY interface. The Honeywell BOS220 compiler provides Fortran capability. This Fortran compiler is an extension of American National Standards Institute Fortran X3.9-1966.

The structure of the emulator parallels the real-time program structure illustrated in Figure 1 up to insertion of signals into the sonar signal processing equipment. This allows for a complete checkout of the software portion of the real-time functions. In addition, predictions of the output signals from the stimulation electronics to the operational sonar equipment were included. This proved to be a very useful adjunct to the emulator for use during factory checkout and acceptance tests prior to shipping the completed trainers to the operational sites, providing a useful check on hardware as well as software performance. The emulator structure is illustrated in Figure 2.

The FBM SOT is functionally divided into six models, which are further divided into modules where required.[2] The major models and modules are as follows:

I. Vehicle dynamics

II. Target spectra
   - A. Active
   - B. Passive
   - C. Acoustic dynamics

III. Noise
   - A. Rain
   - B. Distant Shipping
   - C. Marine life
   - D. Own-ship narrowband
   - E. Broadband independent
   - F. Stripes

IV. Arrays

V. Ocean acoustics

VI. Ancillary

Vehicle dynamics model

The vehicle dynamics model determines the time-varying positions and velocities of the various noise sources. Separate modules are employed in performing the calculations necessary for own-ship, targets, towed array and environmental noise sources (rain, marine life, and distant shipping). In the case of distant shipping, no position keeping is performed during the problem time, and the true bearing of the distant shipping noise source is taken to be invariant. Rain and

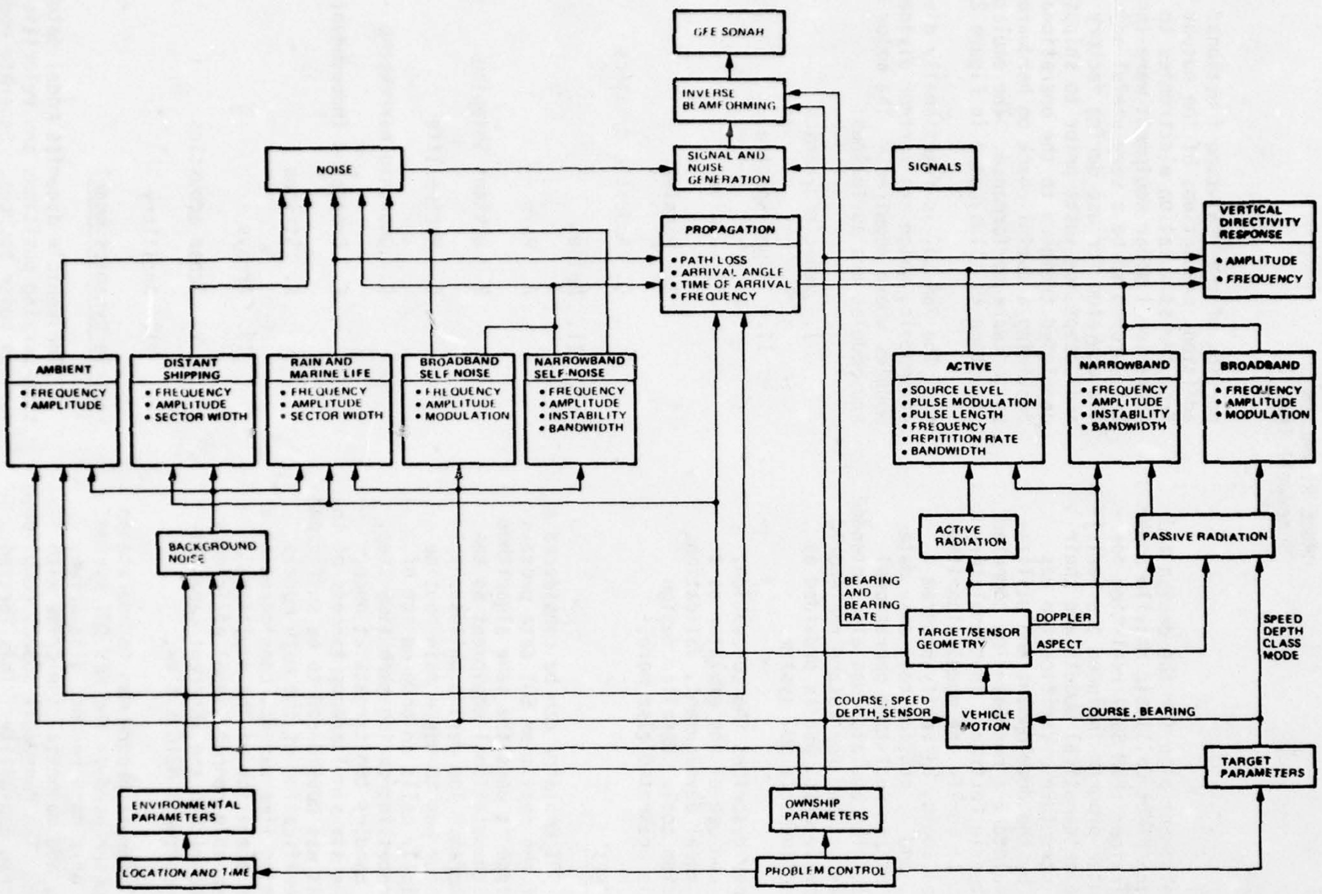

Figure 1. Block Diagram of the FBM SOT

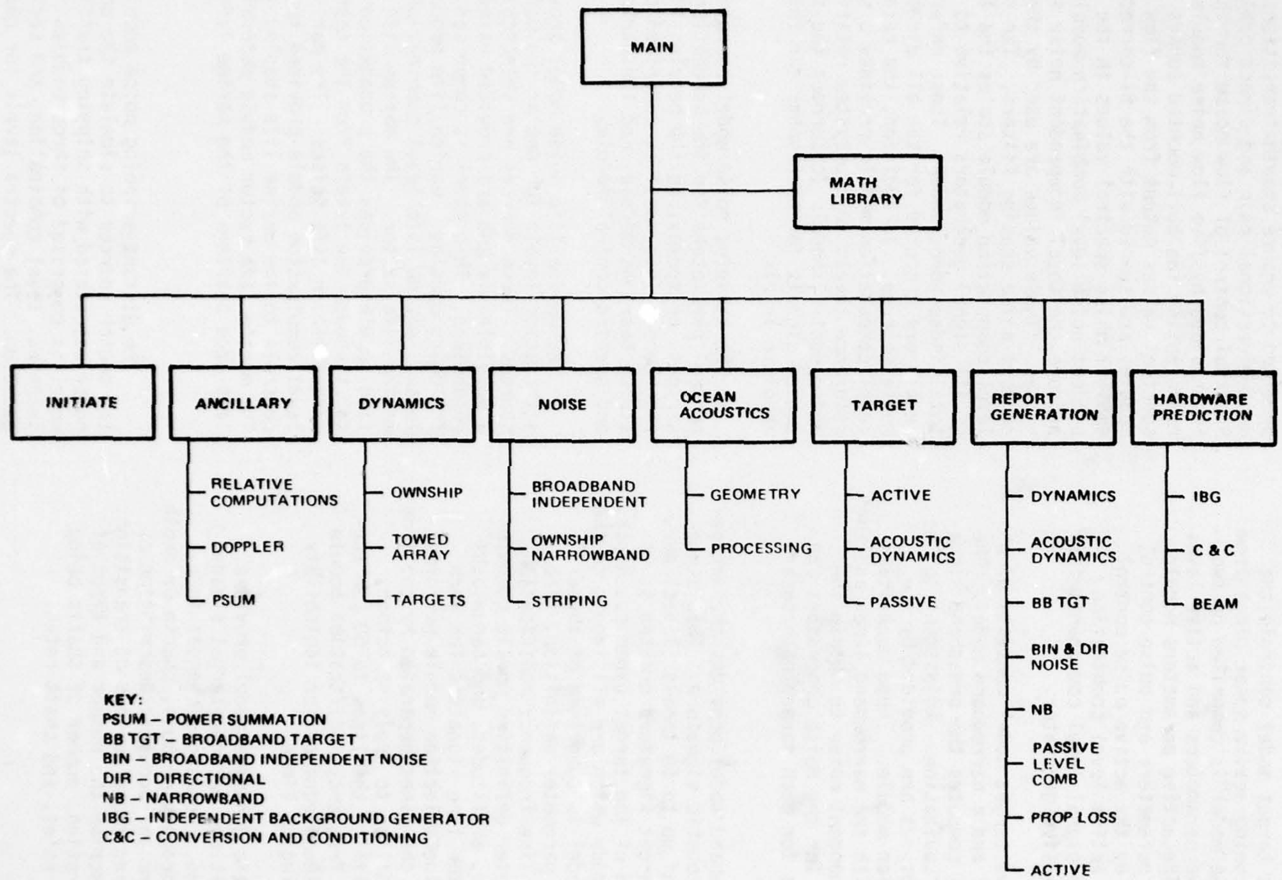

Figure 2. Functional Structure of the Emulator

marine life sector widths are determined in this model.

Target spectra models

The active target model controls the creation of incoming active sonar pings from the target. The model is comprised of two modules: active parameters and active level combination. The active parameters module provides pulse parameters and pulse control signals needed by the active pulse control hardware. The active level combination module combines signal level components for output to the active generator.

The passive target model consists of a broadband model and a narrowband model. The broadband model computes the broadband signature including cavitation. Adjustment to the signature for aspect are provided by the aspect correction module. These quantities are combined with the narrowband lines and the broadband independent noise to obtain the level settings for the noise generators and line generators for each target/path/sonar combination.

The narrowband model provides the narrowband passive acoustic signature. This signature consists of up to 50 tonals (lines) per target. The target signature created is in turn a function of the target dynamics, depth, and operating mode which are all inputs to the model. This model is comprised of three modules: line parameter definition, line selection, and line frequency modification. The line parameter definition module computes the frequencies, amplitudes, and bandwidths that comprise the line signature for each target. The line selection module performs a screening of the lines generated by the line parameter definition to apply selection criteria that limits the lines to 50 per target. The line frequency modification module modifies the line frequency for instability and includes singing lines.

The acoustic dynamics model provides acoustic transitions between target steady state operations. Commanded changes in target speed, propulsion mode, course or depth are used to form the acoustic description of the target during these periods of transition. The outputs describe the number and types of engines in operation, number of shafts being driven, engine rates, and shaft rates.

Noise Models

The broadband independent noise model controls spectral parameters for the generation of noise due to own-ship's flow noise, omni-directional rain noise, and sea state dependent ambient noise. The spectral control of ambient noise is provided by the ambient noise module and is corrected for directivity index (DI). The omni-rain noise module provides spectral levels for each of the sonars which represents the combination of the rain spectrum levels and the DI spectral adjustment for omni-directional noise. Control is provided to ensure smooth transitions between omni-directional rain and directional rain. Spectral control of flow noise for the sonars is provided by five flow noise modules, representing the hull-mounted sonars. The spectral values output from the flow noise modules are summed with the DI-corrected ambient noise spectral values in the independent noise level combination module to produce the total independent noise spectral values. These values are used by the independent noise shaping filters. The reference level computation module scales the levels of all signal generators relative to the total independent power. These reference levels are computed for the all directional noise sources. In addition, the relative level computation module provides a set of reference levels to the system relative noise control module to correct the summed scaled signals for each sonar for the proper absolute levels.

The striping noise model computes control parameters for the generation of stripes, or spokes, on the bearing-time recorders. This model is comprised of the stripe bearings module, and the stripe level and spectra control module.

The marine life noise model provides attenuation levels for one or two marine life sources. These sources are selectable from a possible six and are provided using tape recordings. This model is comprised of the following modules: marine life propagation losses, marine life level combination, and marine life sector. The marine life propagation module provides the propagation loss used to attenuate the levels from the tape recorded marine life noises. The marine life level combination module provides the level controls to the marine life shaping filters. The marine life sector module determines the left edge bearings of the marine life sector.

The distant shipping noise model provides ten sector sources to simulate the anisotropic noise associated with shipping traffic. The model is comprised of three modules: distant shipping, level combination, and sector calculation. The spectra levels for each sector as a function of shipping density is controlled by the distant shipping module. The combining module combines distant shipping source levels, baffle attenuation loss, horizontal sensitivity, and relative reference levels. The sector module provides the left-most bearings associated with the shipping sectors.

The rain model provides the control parameters for the generation of directional rain. The model is comprised of four modules: sector, propagation, noise, and level combination. The rain sector module computes the left edge bearings for five subsectors. Each of the sectors is overlapped at least one degree. The rain propagation module provides the propagation loss used to attenuate broadband signals generated by rain. The rain noise module also provides spectral level control for directional rain noise. A rainfall level associated with a rate of one inch per hour is used. The rain level combination module provides the level controls to the rain shaping filter to set the levels for the directional rain noise.

The own-ship narrowband noise model provides control parameters for the generation of own-ship narrowband noise. These control parameters include line frequency, line level and line bandwidth. The modules contained are own-ship narrowband and level combination.

Array Model

The array model calculates various acoustic parameters required in the process of stimulation signal generation. The model consists of six distinct functions:

1. Inverse beamformer (IBF) delay calculations
2. DI corrections
3. Baffle
4. Hull mask
5. Vertical sensitivity
6. Horizontal sensitivity

The array model utilizes relative target bearing, acoustic path arrival angle, and frequency to determine the appropriate array parameters.

Ocean Acoustics Model

The ocean acoustics model provides the hydroacoustics transfer characteristics of the medium. The data includes angles of arrival, travel time, discrete phase angle, and path loss for each of one or two rays from each target to own-ship and to the towed array. The method of real-time implementation of this model is to precompute the required data and store it on disk files for subsequent real-time access.

Ancillary Model

The ancillary model aggregates several multi-usage and special-purpose modules. The modules include the following: relative computations, power summation, and doppler shift. The relative computations module determines range, bearing, and positional rate relationships between sensors and targets and, upon demand from the Instructor Control Console (ICC) computes closest point of approach between own-ship and a target selected by the ICC. The power summation module is a library function. The doppler shift module adjusts active frequencies from the targets and all line frequencies between own-ship and targets.

The inclusion and integration of all these models in an emulator resulted in approximately 16,000 lines of executable Fortran contained in 156 files and requiring a total memory of approximately 107,000 words.

Emulator Usage

The emulator was used extensively to provide data for real-time program evaluation. It proved to be indispensible for providing test data for integrated model verification. Hand calculation for verification of the real-time program would have been completely infeasible due to the size and complexity of the total program.

Extensive overlaying was designed into the operation of the emulator because of memory constraints. This overlaying procedure resulted in the run time for the emulator being 15 to 20 times real time. This presented no problem for the majority of the model verification runs since they were not dynamic; i.e., data was required at only one instant in time to verify the calculation of radiated and received acoustic levels for specified steady-state conditions. For those runs associated with checking the dynamic performance, overnight running proved to provide adequate blocks of time.

The emulator also served a useful function in the final stages of model design and improvements. This was particularly true for the broadband independent noise model, which is very complex and required several modifications after its initial formulation and checkout. Logical errors in the various models were rapidly detected, and thereby reduced the task of the real-time programmers in attaining a correct program.

The hardware prediction feature previously mentioned offered the choice of six distinct outputs, available one at a time. They were: 1) ambient, 2) target, 3) target and ambient summed, 4) rain, 5) own-ship broadband and 6) own-ship narrowband. A typical example of how the emulator results compared with the hardware outputs is shown in Figure 3 for a typical target.

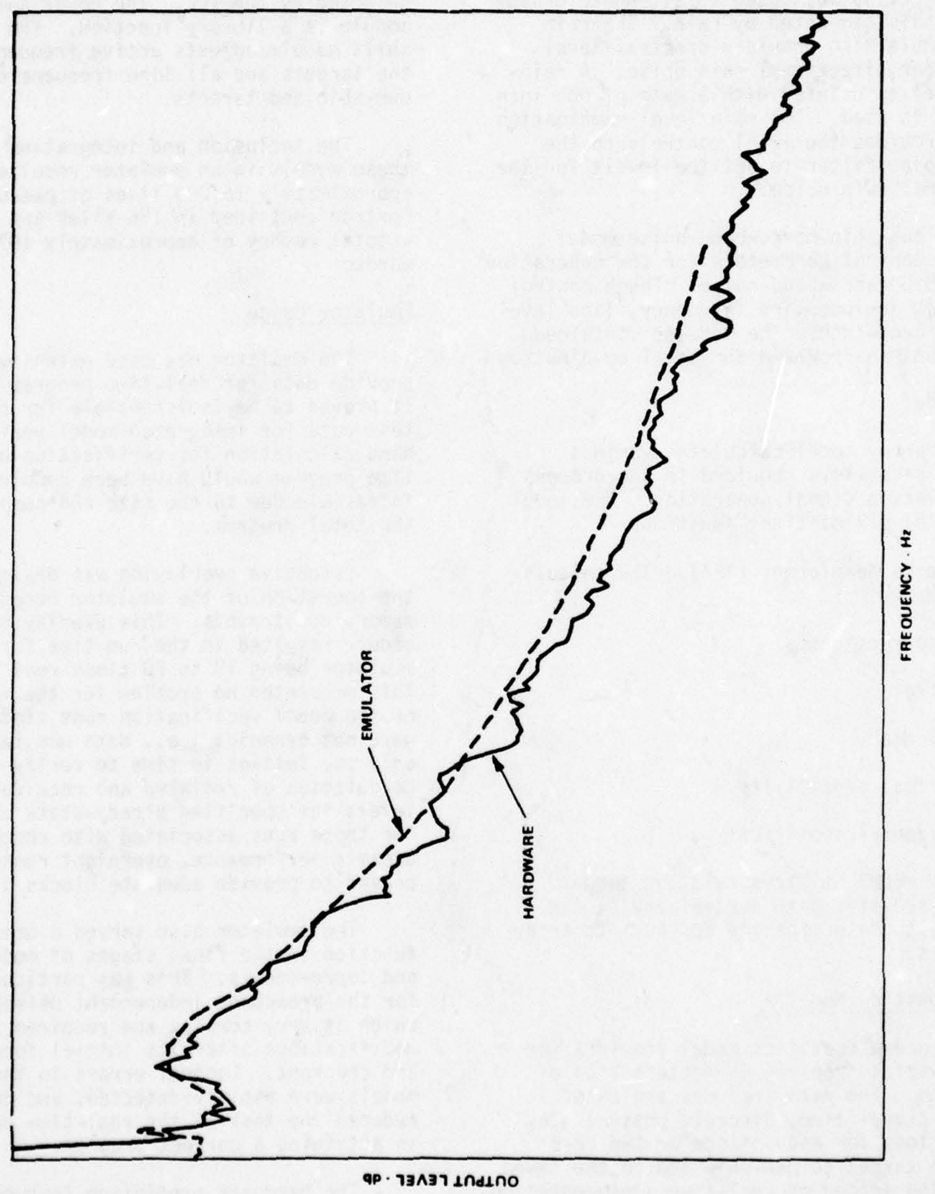

Figure 3. Comparison of Emulator Predicted Sonar Beam Output with Hardware Output for a Typical Target

The output of the emulator provided the geometric data and acoustic generator level settings corresponding to the output from the real-time software. Individual models were verified as well as model interface processes under both static and dynamic system conditions. Nonreal-time tactical scenarios were generated which were then exercised and verified within the operational trainer system. The outputs of the emulator were used as the verification test data, against which the real-time program outputs were compared on a one-to-one basis.

Debug capability provided outputs from each module interface as well as individual internal model data for rapid fault localization. Calculation details of particular sections of the emulator code were made available by including certain cards containing a code number in the input stream. A particular code number would result in the printout of the key calculations within a model, such as broadband independent noise.

CONCLUSION

The emulator proved its usefulness in the development of a large, interactive stimulation device such as the FBM SOT. The operability, from the standpoint of computational time, would have been greatly enhanced by programming the emulator on a large system. This would also have shortened the development time, since some errors inevitably resulted from the extensive overlaying required on the small system. Unfortunately, the need for maintaining security classification precluded the use of a large system by remote terminals.

In spite of these disadvantages imposed by the small computational system available, emulation proved to be a valuable, cost-effective sonar trainer model validation and verification tool.

REFERENCES

1. "FBM SOT Emulator, Increment #1: Design Approach," P. B. Billing, Unpublished Honeywell Preliminary Memo, Honeywell Training and Control Systems Center, Defense Electronics Division, 13 December 1976.

2. FBM Sonar Operational Trainer (SOT) Computer Program Performance Specification (CPPS), Appendix A, Math Model (U), Honeywell Training and Control Systems Center, Defense Electronics Division, 15 December 1977, Contract N00140-76-C-6043, SECRET.

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RECENT ADVANCES IN OCEAN MODELING TECHNIQUES FOR SONAR TRAINERS – FBM SOT

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INTRODUCTION

Realistic simulation of the received signals from ships and submarines is the primary objective of the Fleet Ballistic Missile Sonar Operational Trainer (FBM SOT) built by Honeywell's Training and Control System Center. The sonar suites on board the FBM submarines provide reliable information conveying a target's movement and identity. Acoustic properties of the ocean significantly affect the visual and aural representations of a ship's signal. The ocean medium's variability can be used advantageously in locating and tracking a ship as well as to cause confusion resulting in tactical errors. Recognizing and utilizing various sound propagating characteristics of the oceans is an essential training goal.

REQUIREMENTS OF THE OCEAN MODEL

The SOT is comprised of an instructor control center, a mini-computer complex, nontactical hardware and tactical hardware. The nontactical training hardware provides shaped signals utilizing real-time program computations controlled by an instructor's inputs. Tactical hardware is stimulated by these signals subsequent to their being inverse beamformed. The SOT classroom is a duplication of the sonar suite of FBM submarines, permitting extremely realistic training on bearing time recorders, cathode-ray tube (CRT), spectrum analyzers, lofargram recorders, and audio headsets.

The ocean acoustic model must behave realistically in a wide frequency range and exhibit ocean acoustic characteristics typically exploited by the sonar arrays and their sophisticated signal processors. Therefore, sound transmission in surface ducts, convergence zones, deep sound channels, and shadow zones must be simulated. The acoustic model is also required to furnish the data to simulate interference patterns which can be used to determine a ship's closest point of approach (CPA). Figure 1 illustrates the spectrum history of a ship as it passed the CPA as shown on a test spectrum analyzer.

Data obtainable from ray theory models is in the most convenient form for trainer modeling. Several acoustic computer program models such as Ray-Normal Mode Theory (RAYMODE), Navy Interim Surface Ship Model (NISSM), or Continuous Gradient Ray Tracing System (CONGRATS V) provide ray information including path travel time, angle of arrival and phase angles, as well as propagation loss. Path loss information is used to attenuate signals as a function of frequency, to represent accurate detectability. Path arrival angles convey location information; multipaths can reflect the condition of detecting a target on more than one beam. Interference patterns are sensitive to the time delays between arriving paths, their phases and their relative amplitudes.

The contracting agency, the Naval Underwater Systems Center, selected a modified version of the CONGRATS V program,[1] developed by Dr. Henry Weinberg, to supply the primary acoustic path data. The modified program computed eigenray data valid in the frequency domain of the sonars and in the environmental domain of the FBM submarines. The summation of the eigenrays between a source and a receiver produces the phenomena of convergence zone, surface ducts, deep sound channels, and shadow zones. The presence of these phenomena is dependent on the sound velocity profile, the bottom type, sea state, source to receiver range, source depth, receiver depth, and the signal frequency. Given specific values for these parameters, CONGRATS V generates scores of paths in nonreal time on a UNIVAC 1108 computer. Table 1 illustrates the numerical form of data output by the CONGRATS V program at a range for a specific source and receiver depth combination at 250 Hertz. The sound velocity profile is given in Figure 2. Figure 3 is a diagram of the rays emanating from the source.

To achieve real-time requirements of updating at a one-second rate while retaining CONGRATS V accuracy, data is precomputed and stored on disk for recall during training. Data bases for up to 12 sound velocity profiles each with two bottom types and sea states are available to the instructor. A logical record of information is stored for each receiver/source range and depth pair combination of a data base grid point. The record contains propagation losses at each of 30 1/3 octave frequencies for one or two paths. Also included are values for a path's geometric features: arrival angles, travel times, and discrete phases. The geometric features are assumed to be frequency independent.

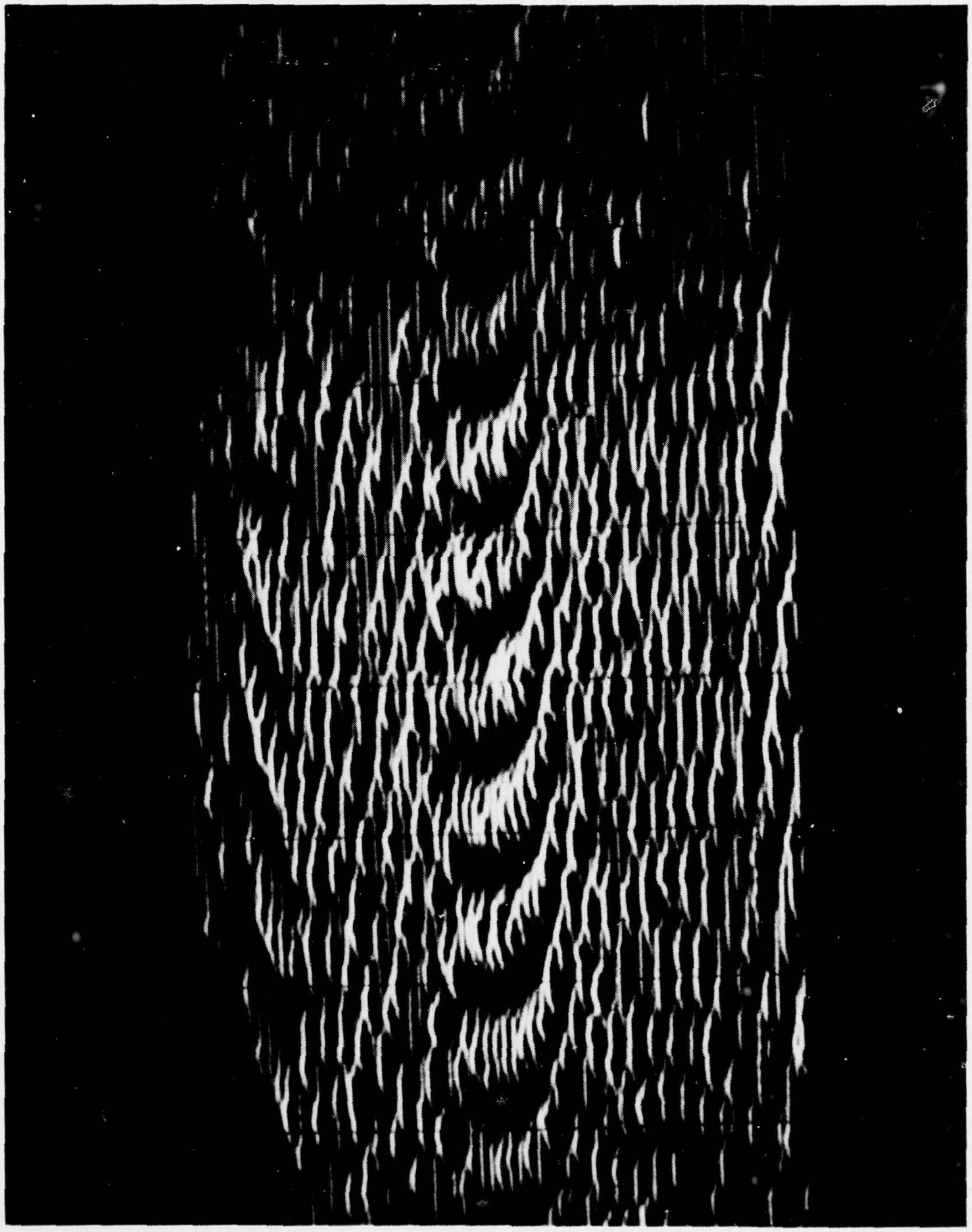

Figure 1. CPA Interference Pattern

Table 1. CONGRATS V Eigenray Data

Range (Kyd)	Frequency (Hz)	Time (Sec)	Source Angle (Deg)	Target Angle (Deg)	Loss (db)	Phase (Deg)
46.00	250.00	27.579512	12.704108	-12.829039	111.158517	15.6673
46.00	250.00	27.577041	11.873343	-12.007204	93.170468	2.3768
46.00	250.00	27.728279	.818916	- 1.978295	109.050736	-148.4483
46.00	250.00	27.606488	12.719545	12.844322	109.986238	-159.1082
46.00	250.00	27.602059	11.589337	11.726534	92.831084	-180.0000
46.00	250.00	27.733551	.818916	1.978295	105.116444	-278.1175
46.00	250.00	27.624273	-12.729931	-12.854603	109.103580	-159.7823
46.00	250.00	27.618164	-11.386219	-11.525900	92.665692	-180.0000
46.00	250.00	27.735632	- .818916	- 1.978295	102.323842	-307.2848
46.00	250.00	28.293893	16.903569	-16.996447	104.929779	-180.0000
46.00	250.00	27.743140	2.510893	- 3.089612	97.178627	-245.2994
46.00	250.00	27.743140	2.510893	- 3.089612	92.342027	-385.3410
46.00	250.00	27.651324	-12.770833	12.895096	136.050659	-349.6331
46.00	250.00	27.642172	-11.073878	11.717554	92.392936	-360.0000
46.00	250.00	27.740905	- .818916	1.978295	100.638495	-477.9066
46.00	250.00	28.329292	17.100242	17.191993	104.988511	-360.0000
46.00	250.00	27.751066	2.736899	3.275880	103.827311	-414.0223
46.00	250.00	28.352898	-17.228818	-17.319844	105.030611	-360.0000
46.00	250.00	28.388828	-17.415368	17.505364	105.094591	-540.0000
46.00	250.00	27.745878	- .538281	- 1.879576	134.131605	-793.0954
46.00	250.00	27.745926	.345626	- 1.833750	125.575147	-803.7864
46.00	250.00	27.750934	- .270971	1.821167	134.450928	-965.7295

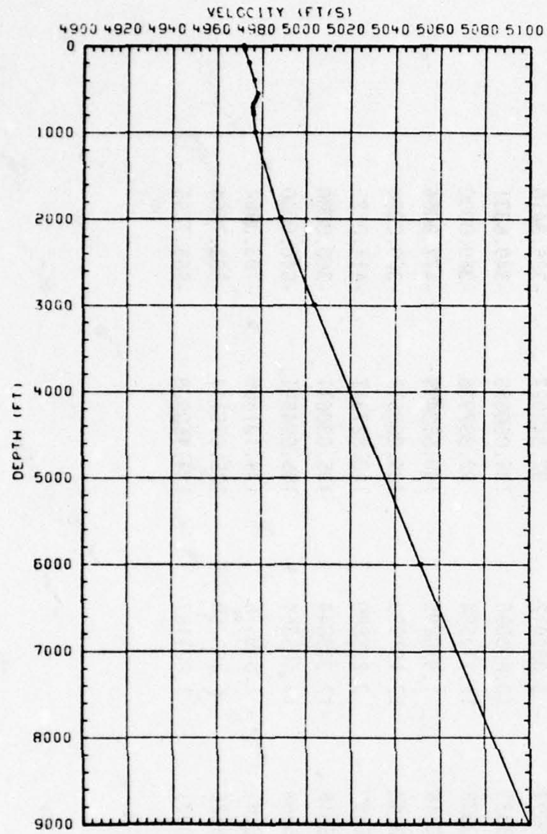

Figure 2. Sound Velocity Profile

The trainer ocean acoustic model problem was to retain the important acoustic features modeled by the CONGRATS V program while simulating only two acoustic paths for real-time training scenarios. Since many CONGRATS V generated eigenrays exist between the source and receiver, the determination of the optimal two-path data is critical.

DEVELOPMENT OF A TRAINER ACOUSTIC RAY MODEL

Initially, the trainer design proposed to match the coherent summation of all the CONGRATS V eigenrays generated between the source and receiver. Government specifications would be met if the coherent sum of the two data base paths at each of the 30 1/3 octave frequencies equalled the CONGRATS V sum as calculated from:

$$N = 020\log_{10}\left|\sum_j (10^{-0.05N_j})(e^{i(2\pi f t_j + \emptyset_j)})\right|$$

where,

- N = summed propagation loss of all eigenrays between a source and receiver
- N_j = propagation loss for the jth eigenray (dB)
- f = frequency (Hz)
- t_j = travel time for the jth eigenray (seconds)
- $\emptyset_j$ = phase angle of the jth eigenray (radians)

This constraint was believed necessary in order to preserve the well-known Lloyd's mirror coherence effect that the CONGRATS V data could reproduce. The distance between grid storage points cirtically depended on this requirement and consequently the size and cost of producing a data base.

The proposed trainer design divided the CONGRATS V eigenrays into two groups: those arriving at the receiver from the upward direction and those arriving from the downward direction. One of the strongest rays from each group was selected for data base storage of its geometric features.[2] The propagation losses of the fastest traveling path were computed at each frequency based on the absolute and relative strengths of the two selected rays. To meet specification requirements, the computation of the path loss associated with the slower ray employed an inverse coherent summation algorithm at each frequency. The computation utilized the coherent summed propagation loss of all the CONGRATS V eigenrays, the fast path's loss, and the times and phases of the two selected paths. Thereby, the satisfaction of specification requirements were ensured. However, data generated from this approach failed to stimulate the SOT system satisfactorily. The division of rays according to direction was too restrictive for all environmental conditions. Large variations in the coherent levels associated with each ray at adjacent frequencies and ranges produced unrealistically discontinuous aural and visual effects. The normally stable amplitude of individual rays had to be retained (at the expense of not exactly matching the CONGRATS V coherent levels) in order to realistically stimulate the inverse beamformers with signals generated in real time. The tactical beamformers could then receive signals which exhibit realistic frequency and time characteristics.

Recognition of these shortcomings led to a reanalysis of the system needs and the data generated by CONTRATS V. Subsequently a new method was designed to generate an effective two path-training data base. The algorithm is compatible with most ray theory models.

THE TWO-PATH ALGORITHM

The two-path selection criteria endeavors to reflect the geometric features of the dominating CONGRATS V eigenrays. The dominating eigenrays do, of course, change as a target enters different transmission regions, such as surface ducts or shadow zones. Because the SOT data base is limited

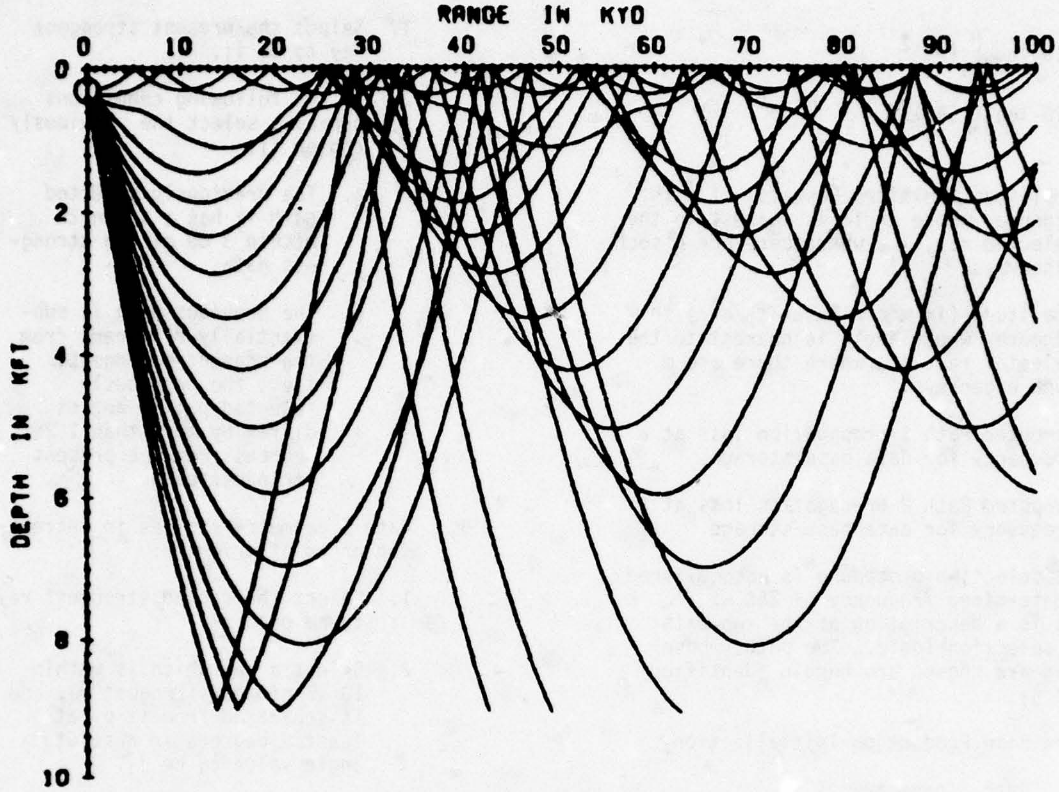

Figure 3. CONGRATS V Ray Diagram

to two-path information selected at distinct points in the ocean, occasional discontinuities in the data may cause abrupt transitions. A real-time lag smoothing process alleviated these abrupt shifts between depth and range storage points.

Before describing the mechanics of the data base algorithm, some knowledge of the CONGRATS V eigenray data is required. Certain mathematical conditions cause the CONGRATS V program to produce imaginary rays which are identical to each other in angles and time as illustrated in Table 1. Preferably, the geometries of the two selected rays should be different and indicative of two strong modes of signal transfer between a source and receiver. For example, there may be strong direct paths, several strong surface bounce paths and some weak bottom bounce paths. Since the algorithm is limited to selecting two rays, the best selection for training purposes would be a direct path and one of the surface bounce paths. For the SOT data base, CONGRATS V generated up to 65 eigenrays between a source and receiver. Typically, as the range or depths vary, the eigenrays geometry varies continuously and smoothly. Therefore, the geometries of the two stored rays can be directly taken from two CONGRATS V eigenrays. Constraints imposed on integration and interpolation technques, employed by the CONGRATS V program to reduce execution time, cause an eigenray's amplitude to fluctuate slightly. Artifical switching of selected eigenrays caused by such fluctuations is avoided by saving and comparing the previous range's selections to the present selections.

Each CONGRATS V generated eigenray's amplitude is power summed into one of two groups, yielding the two propagation losses associated with the stored paths at each frequency. Power summation results in smoother path loss curves than coherent summation, while yielding more accurate detection levels than obtainable from a single eigenray. The two-path selection algorithm completely defines the geometries of each path. Those rays closest in absolute angle to one of the selected paths get summed together with that path. The total noncoherent energy of the eigenrays are thereby retained at each frequency. The path losses associated with each ray are computed as follows:

$$N1 = -10 \log \sum_{i=1}^{n} (P_i)^2$$

$$N1 = -10 \log \sum_{j=1}^{m} (P_j)^2$$

where,

P_i = Amplitude (in micro Pascals) of i th eigenray whose angle is nearest to the selected ray, i_1, wherethere are n such eigenrays.

P_j = Amplitude (in micro Pascals) of j th eigenray whose angle is nearest to the selected ray, j_1, where there are m such eigenrays.

N1 = Computed Path 1 propagation loss at a frequency for data base storage.

N2 = Computed Path 2 propagation loss at a frequency for data base storage.

The selection procedure is accomplished at a predetermined frequency of 250 Hz. Following is a description of the two-path geometry selection logic. The paths whose geometries are chosen are herein identified as i_1 and j_1.

I. Data Base Production Initialization

A. Path 1 geometry:

Select the strongest ray (i.e., with greatest magnitude based on rms amplitude) to be i_1. Store its angles, time, and phase to the nearest 180 degrees (SOT hardware constraint).

B. Path 2 geometry:

Select the strongest ray which is at least 3 degrees separated from i_1 in absolute angle value and within 10 dB of its strength. If such a ray doesn't exist, select the second strongest path as j_1.

C. Propagation losses:

1. At each frequency power sum all paths i, whose angles are closest in absolute angle value to selected path i_1. Store those values of N1.
2. Likewise, power sum all paths j and store those values of N2.

II. Subsequent Data Points

A. Path 1 geometry choices in increasing priority order:

1. Select the present strongest ray to be i_1.
2. If the following conditions prevail, select the previously chosen i_1.
   a. The previously selected path i_1 has a strength within 3 dB of the strongest path.
   b. The previous path is substantially different from the present strongest; i.e., the previously selected path's angles differ by more than 1.25 degrees from the present strongest path.

B. Path 2 geometry choices in increasing order of priority:

1. Select the second strongest ray to be path j_1.
2. Select a ray which is within 10 dB of the strongest ray and is separated from it by at least 3 degrees in absolute angle value to be j_1.
3. If the previously chosen i_1 is to be stored, select the strongest ray which is within 10 dB of it and separated at least 3 degrees in absolute angle value to be j_1.
4. If the following conditions prevail, select the previously chosen path j_1.
   a. The previously selected path j_1 has a strength within 3 dB of the highest priority present choice for path j_1.
   b. The present highest priority choice for path j_1 and the previously chosen path j_1 differ substantially; i.e., their angles differ by at least 1.25 degrees.

C. Propagation losses:

1. At each frequency, power sum all paths i. Store those values of N1.
2. Likewise, power sum all paths j. Store those values of N2.

III. Single-Path Data

Data base logical records for ranges in excess of 70 kiloyards contain only one-path information since the sonar equipment is not as sensitive to multipath effects at distant ranges. The strongest path's angles, time and phase are stored. The stored propagation losses are the total CONGRATS V eigenray power sums at each of the 30 frequencies.

DATA BASE PERFORMANCE

Data bases for the various specified sound velocity profiles, sea states, and bottom types are currently being generated on the UNIVAC 1108 computer. One data base has been tested within the system. Favorable responses concerning its convergence zone and surface layer behavior have been received from the instructor-user community. Interference patterns are successfully produced on CRT spectrum analyzers and gram chart recorders. A picture of a target at CPA with an interference pattern is presented in Figure 1.

CONCLUSION

The effectiveness of using fixed ocean acoustic multipath data bases for advanced sonar training will emerge as the students train on the recently delivered trainers. The algorithm presented in this paper can easily be extended to select a greater number of paths for future, more sophisticated trainers. It is compatible with several propagation models and yields comparable ocean characteristics while functioning in real time.

REFERENCES

1. Weinberg, H., Generic Sonar Model, NUSC Technical Document 5971, January 1979

2. Sturm, M. and Frost, I., "An Approach to Stimulation of Ocean Multipath Phenomena for Sonar Training," 1976 NTEC/Industry Symposium.

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ALGORITHMIC PRESCRIPTIONS
FOR
INSTRUCTIONAL SYSTEMS DEVELOPMENT

SUZANNE E. SAX and JOHN M. MOSCICKI
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INTRODUCTION

The algorithmization of instruction has gained prominence since the introduction of the concept to education. Algorithms are generally considered to be a sequence of operations applied to any problem within a given class of problems which, when followed, guarantee an expected result.

Algorithms, in the strict sense of the word, possess these properties of generality and resultivity. However, the concept of algorithmization has widespread implications for education in applications where such precision is not possible. Landa (1974) has termed algorithms used for such purposes "algorithmic prescriptions". To distinguish algorithmic prescriptions from strictly mathematical algorithms, Merrill (1977) labels them as "heuristic procedures". While recognizing that there are such distinctions between mathematical and prescriptive algorithms, this paper will refer to both classes of procedures as algorithms.

An algorithm may take various forms: (1) prose test, (2) numbered steps, (3) question lists, (4) branching booklets, (5) flow charts, (6) directed graphs, (7) decision tables, etc. (Bunderson, 1970). Coscarelli (1978) discusses the merits of different representations of algorithms noting that the form of representation may influence one's problem solving tactics. The flow chart format is proposed as most appropriate for representing complex procedural operations. The flow chart and numbered steps formats were selected to represent the algorithms presented herein.

Algorithms have a number of educational applications:

(1) Application for the student - Algorithms may be written as step-by-step procedures for problem solving, as in multiplication of multi-digit numbers. If the student follows the algorithm correctly, s/he will obtain the correct result. However, merely stepping through an algorithm may not guarantee learning. Gerlach, Reiser, and Brecke (1977) state that a learner does not need to understand the algorithm in order to apply it. Similarly, P. Merrill (1977) notes that a student may perform a set of mechanical actions in rote fashion. This need not be the case. The authors describe the positive benefits which may accrue through the use of algorithms. The student may gain insight into the problem by seeing the task as a whole, and by having the problem steps designated explicitly.

Even a greater benefit may be gained via algorithms when the student is involved in the actual construction of the algorithm for a given problem. By participating in the process of generating an algorithm, the student is engaging in high-level problem solving behavior which has great potential for transfer.

(2) Applications for the designer - The same benefits as described for the student apply to an even greater extent to the instructional designer. Landa (1977) notes that algorithms are a legitimate aid to both the student in problem solving and the teacher in teaching. Algorithms may be written which describe what the teacher's activities should be in order to effect learning by the student.

The discipline required for algorithm construction can greatly improve the quality of the instruction. The teacher/designer, in essence, conducts a task analysis, the formal output or representation of which is an algorithm.

Kopstein (1974) remarks that algorithmization provides the bridge between educational objectives and effective instruction, and is particularly compatible with such forms of instruction as programmed texts, computer-managed instruction (CMI) and computer assisted instruction (CAI). "Algorithmization provides the methodology - the detailed how to - for instructional design" (p. 13).

APPROACH

The present paper proposes a model of lesson development which utilizes three functional classes of algorithms. The particular application is the Naval Electronic Warfare Training System (NEWTS), involving the training of military personnel in electronic warfare equipment operation, and radar signal analysis and identification.

The training takes place on a simulator-trainer driven by computer-assisted instruction (CAI). Due to the nature of the

instruction, which is largely procedural, and the delivery system, design activity was directed to an algorithmic approach to streamline and facilitate instructional development while providing standardization and consistency between lessons. The algorithmic process also insured that lesson presentation would be logically ordered and all integral components would be included; content errors and omissions could be detected, as well. The algorithms provided a blueprint for lesson construction.

Three classes of algorithms, comprising a system for developing instructional materials, emerged as necessary and sufficient for the NEWTS lesson development effort. The classes of algorithms were:

1) Learning Algorithm - prescriptive of the teaching strategy utilized.
2) Instructional Flow Algorithm - descriptive of the lesson flow, including paths and options.
3) Task/Procedures Algorithms - descriptive of the lesson content.

GENERAL LEARNING MODEL ALGORITHM

The first class of algorithms is the General Learning Model Algorithm (Figures 1 A-D). This class is comprised of algorithmic prescriptions by which an instructional designer can systematically arrange instructional events according to principles of learning theory. Since these prescriptions are concerned with learning principles, they are independent of subject matter content and, therefore, can be used to determine how to teach regardless of what is to be taught.

The arrangement of the General Learning Model Algorithm is along four categories of learning: Association, Discrimination, Relationships, and Applications. These learning types are related to the types described by Gagne (1977) but represent a reformulation of learning principles into a synthesized scheme.

Association

The first type of learning is association (Figure 1A), which is defined as the establishment of a bond between a stimulus and a response, or label, paired in temporal contiguity within a given structure or context. Association then is the most basic category, and it is here that a student learns the name of a stimulus object or learns the appropriate response when presented a stimulus.

Discrimination

The second learning type is discrimination (Figure 1B) in which a situation is designed to test and strengthen a previously acquired association. Although discrimination may exist at a much lower level, when a target stimulus object is discriminated from the rest of the environmental stimuli, the level of discrimination of concern here presupposes the existence of a learned association. When a number of discriminations are required from the learner, this arrangement is described as a multiple discrimination (Gagne, 1977; Davies, 1973). At this point the student has learned to identify a stimulus from a group of stimuli and is prepared to progress in the learning process to the learning of concepts or relationships.

Relationships

The establishment of the relationships (Figure 1C) between the learned associations within some given context(s) or classification scheme(s) defined by a predetermined, unifying principle(s) constitutes relationships learning, the third type of learning. It is at this point that a student learns to classify related stimuli into groups and to distinguish among these groups based upon the unifying principle(s). Gagne (1977), and Gagne and Briggs (1979) define the process by which a student is able to assign stimuli to a class based upon physical properties as the learning of concrete concepts. If a student learns an abstract principle as the definition of a group, Gagne, and Gagne and Briggs define this capability as the learning of defined concepts or rules. The distinction between the types of concept learning and rule learning is a valid one. However, in accordance with the principle of Occam's razor, the present scheme describes the phenomena of learning concepts and rules as a single category; i.e., relationships. This grouping emphasizes the unifying principles involved in relationships learning which is more encompassing than the lower level of physical properties relationships. The unifying principles form the subject matter which is learned regardless of the complexity or rationale of the stimulus relation. This approach should facilitate utilization of the techniques in this segment of the General Learning Model Algorithm in an educational application.

Application

Following the acquisition of relationships the student should be required to apply them. This involves the arrangement of learning situations which require the exercise of the learned relations under a variety of conditions to establish the appropriate application skills. In application learning (Figure 1D), the problem is presented with minimal cues and prompts. The learner then

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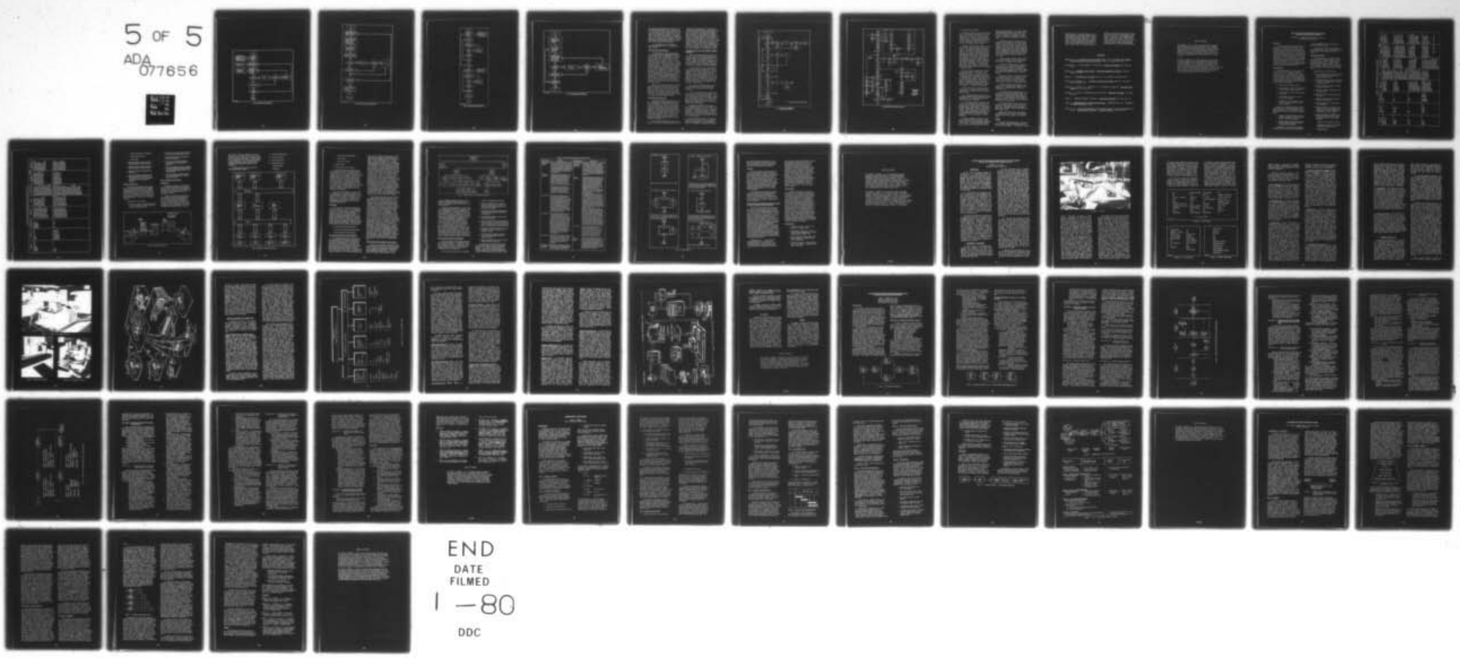

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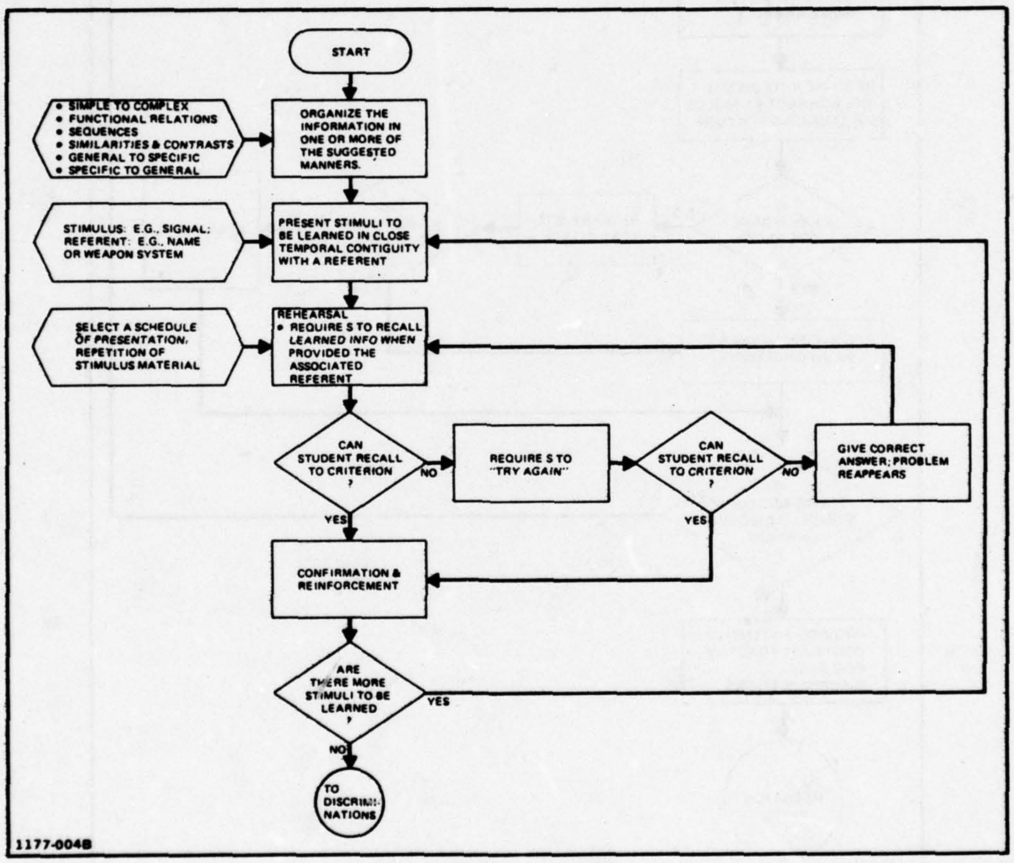

Fig. 1A Association Learning Algorithm

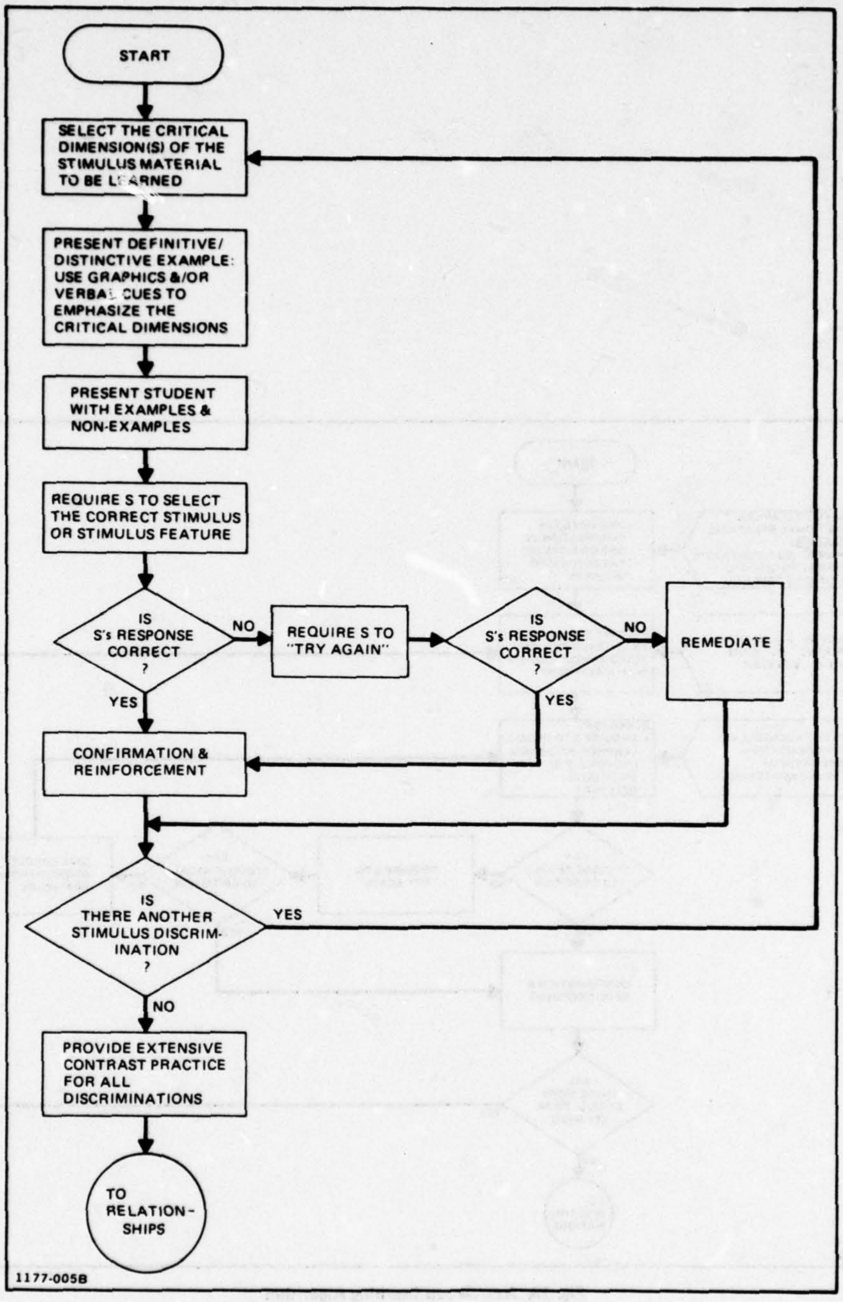

Fig. 1B Discrimination Learning Algorithm

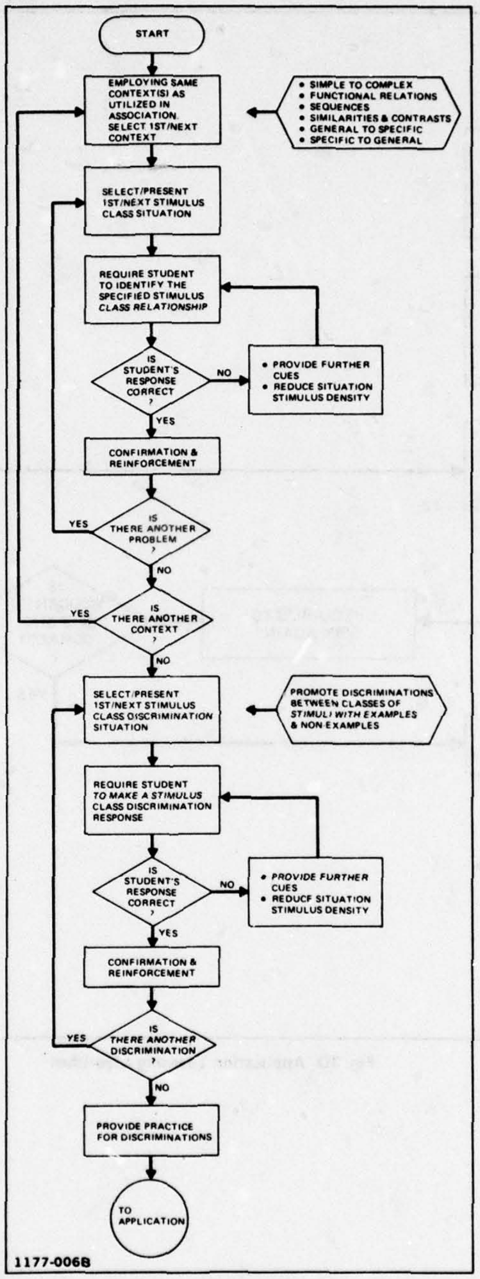

Fig. 1C Relationships Learning Algorithm

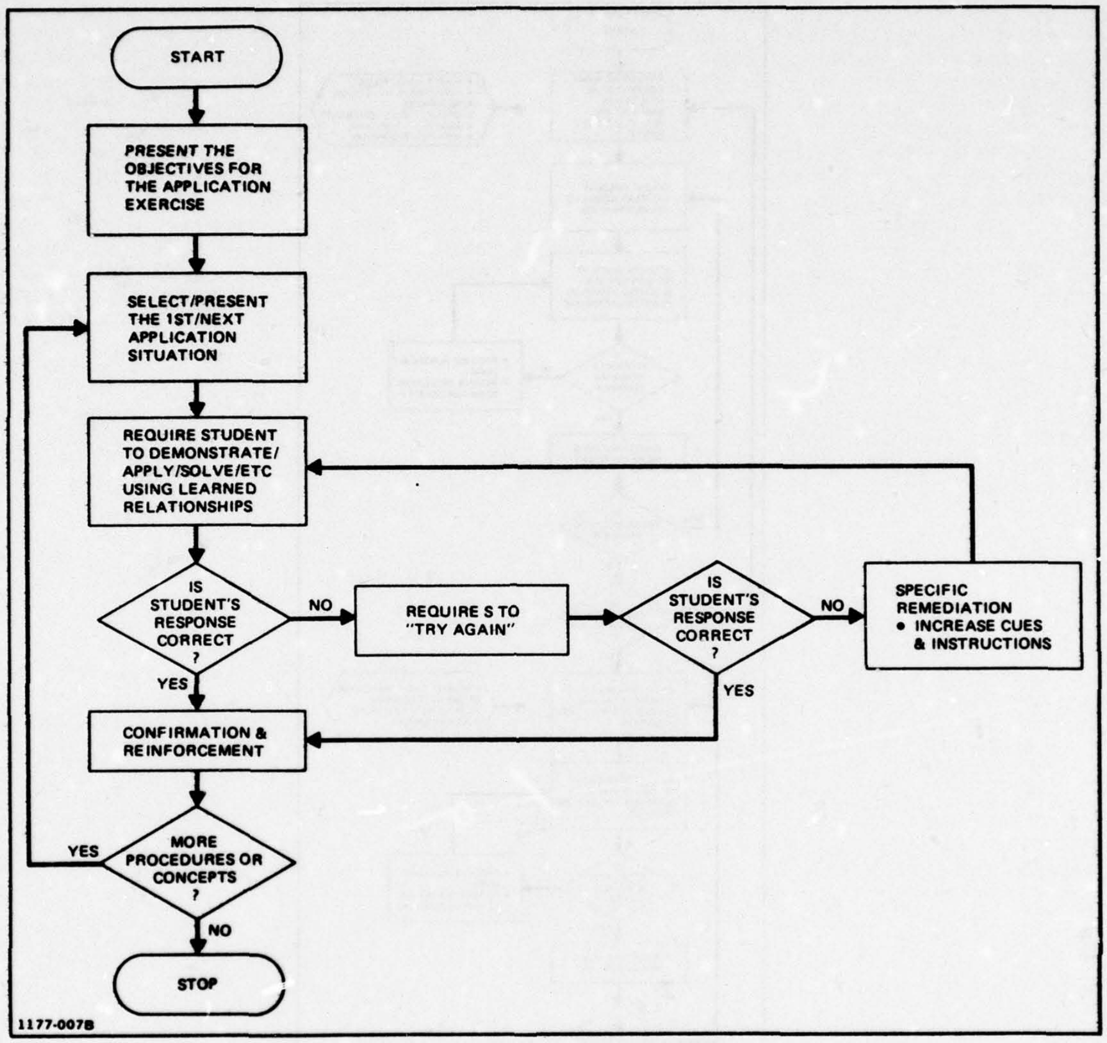

Fig. 1D Application Learning Algorithm

must derive and demonstrate the solution to the problem based upon his/her understanding of the previously learned relationships. Under some conditions the learner will only be required to substitute answers to like problems. This type of application is exemplary of exercises which can be arranged in the same manner as a problem solving exercise in which the student must formulate a solution based upon his/her learned relationships.

The implementation of the General Learning Algorithm will be illustrated in a later section.

INSTRUCTIONAL FLOW ALGORITHM

Like the General Learning Algorithm, the Instructional Flow Algorithm (Figure 2) is a concept which is independent of subject matter. This type of algorithm can specify the framework for a type of lesson, e.g., tutorial, drill, or test, as well as illustrate the control mechanisms within a lesson, such as decision criteria, options, and paths through a lesson. The Instructional Flow Algorithm provides a description of the manner in which these control mechanisms operate on the lesson components to regulate lesson execution. As a result, the specific format and possible permutations of lesson components can be systematically determined *a priori* thereby facilitating the development of the instruction. The operations performed by the control mechanisms and their consequent effects on lesson execution can be validated empirically, and any indicated modifications can then be made.

Additionally, the Instructional Flow Algorithm concept can be used to describe the manner in which all of the lesson types operate conjointly within a curriculum. This feature is very useful for the illustration of options for branching around nonrequisite lessons or lesson types, and decision criteria for student progress between lessons.

TASK/PROCEDURES ALGORITHMS

The algorithms described above are content independent and provide guidance for a lesson developer's construction of a framework for instruction. Thus, the content of a lesson can be formatted according to the guidelines established by these algorithmic concepts. Algorithms present information systematically to promote effectiveness, efficiency, and consistency when utilized for instructional purposes. This is the role of the Task/Procedure Algorithm (Figure 3): to provide a systematic representation of the content of instruction.

Task/Procedure Algorithms reflect the results of a task or procedure analysis which identifies the components of target goals. In developing the instruction based upon the analysis, a complex task may be taught as a set of subtasks or as an entire procedure. When the task is broken down into subtasks these subtasks may be separately taught, each with its own objective(s). If the task is taught as a whole, then the task itself serves as the objective. When this is the case, the Task/Procedure Algorithm may be explicitly taught; or it may serve as the systematic program, or structure, of content presentation and thereby implicitly learned by a student as s/he is engaged in the learning process.

ILLUSTRATION OF USE OF THE GENERAL LEARNING ALGORITHM

While the function and utilization of the Lesson and Task/Procedure Algorithms are readily apparent, the implementation of the Learning Algorithm may not be so clearly evident. Thus, the following examples drawn from the NEWTS application are intended to illustrate the use of the General Learning Algorithm in systematic lesson development.

In applying the General Learning Algorithm to the content defined by the Task/ Procedures Algorithm, one may use a "micro" approach in which each subtask comprises an objective and is treated by the entire learning algorithmic sequence, or a "macro" approach in which the composite task is the objective and is treated by the sequence of learning algorithms. Either one or a combination of the two may be appropriate for any given lesson topic.

Two "types" of learning tasks will illustrate the General Learning Algorithm: (1) procedural learning and (2) factual learning.

(1) To illustrate the use of the Learning Algorithm in teaching a procedure, examine the topic of acquiring a signal. There are a number of steps, or procedures, which must be performed. There is a prescribed sequence for those steps as well. Thus, in treating this topic, both a micro and macro approach may be employed.

A suggested treatment utilizing the micro approach might be the following: Each step would be treated as a topic. Association would be established by describing the procedure. A problem situation, a signal, would be devised in which the student would be required to perform the procedure with explicit instructions.

Discrimination will occur in that the student must actively select the appropriate piece of equipment from among other pieces of equipment, and adjust the control

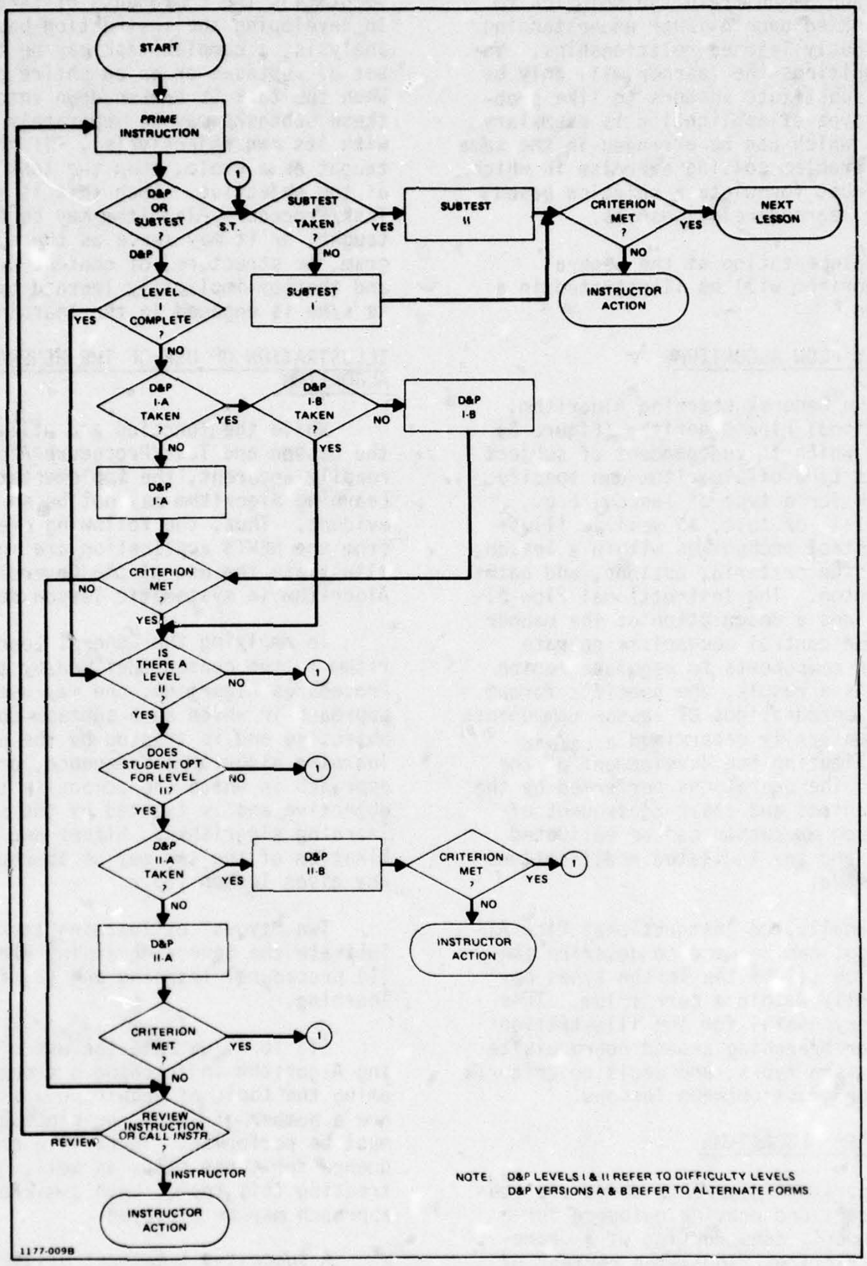

Fig. 2 Instructional Flow Algorithm
An Example from NEWTS

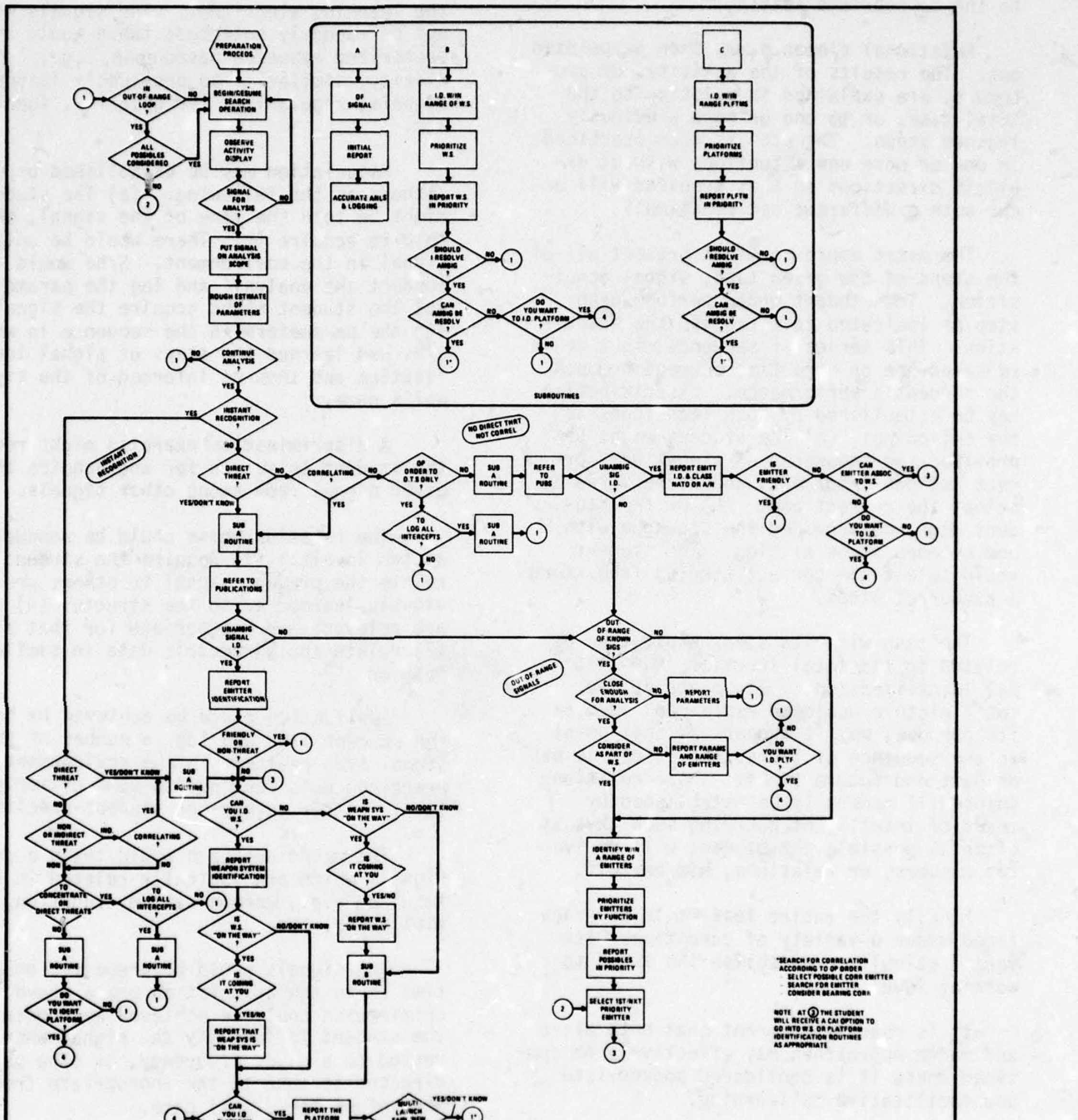

Fig. 3 NEWTS ESM Task/Procedure Algorithm

to the appropriate setting.

Relational elements may then be pointed out. The results of the activity, or procedure, are explained in relation to the total task, or to one or more previously learned steps. The step is then practiced in one or more new situations without explicit directions so that transfer will occur with a different set of stimuli.

The macro approach might present all of the steps of the given task, signal acquisition. The student would perform each step as indicated to establish the association. This series or sequence might be repeated one or more times depending upon the student's performance. Discrimination may be established by such techniques as the following: (a) The student might be provided two sequences of steps, one correct and one incorrect, and be required to select the correct one. (b) Or the student might be provided the sequence with one or more steps missing. The student would select the correct step(s) from among a number of steps.

The task with its steps would then be related to the total function; e.g. signal identification. Its place in the total picture would be explained, such as its purpose, why it appears at that point in the sequence of tasks, the effect it has on past and future tasks. These relationships will generally be established by means of intelligent querying such that as often as possible the student will derive the answers, or relations, him/herself.

Finally the entire task would be practiced under a variety of conditions with varied stimuli to establish the skill to a working level.

It is readily apparent that both micro and macro approaches may effectively be combined where it is considered appropriate and facilitative to learning.

(2) The above example illustrates the use of the algorithms in performing a procedure, such as those steps necessary to perform signal identification. The student has been learning the steps, but not the signals. Once these steps are established in the student's behavioral repertoire, it is then appropriate to teach the signals, themselves. This we may deem as factual learning.

A similar treatment to that of procedural learning will be provided to illustrate micro and macro algorithmic approaches to this topic. The micro approach might take a single signal through the steps of the learning algorithms. The signals would not be randomly selected; there would be a prescribed sequence based upon, e.g., complexity, similarity to previously learned signals, regularity, irregularity, function, etc.

Association may be established by such methods as the following: (a) The student might be told the name of the signal, then told to acquire it. There would be only one signal in the environment. S/he would then conduct the analysis and log the parameters. (b) The student might acquire the signal and log the parameters in the sequence in which s/he had learned the steps of signal identification and then be informed of the signal's name.

A discrimination exercise might require the student to search for and acquire the given signal from among other signals.

The relation phase could be conducted at two levels: (1) Require the student to relate the present signal to others previously learned or to the structure(s) which are relevant and appropriate for that signal; (2) relate the parametric data in similar fashion.

Application could be achieved by having the student find and log a number of that signal type resident in the environment. Practice could continue to some criterion level (either author- or student-specified).

The macro approach would teach a set of signals which are logically related in some fashion; e.g., weapon system, function, similarity, etc.

The signals would be presented one at a time as in the association phase above. Discrimination could be achieved by requiring the student to identify the signal when directed to a given frequency, or s/he may be directed to tune to the appropriate frequency when given the signal name.

The relational phase would involve the relating of each signal to those of the set according to function, threat, parametric data, etc. Parametric data may be emphasized where appropriate.

Application would require the student to increase the skill level in locating and identifying specific signals to a criterion level.

SUMMARY

The above approach describes a system of three classes of algorithms which guide instructional development. The General Learning

Model Algorithm is representative of four learning types and provides guidance for the arrangement of instructional events according to learning theory principles. Instructional Flow Algorithms identify the framework of a lesson and specify the operations of the control mechanisms of the lesson. Both of these types of algorithms are independent of content matter and provide guidance for the design and development of any type of instruction. Task/Procedure Algorithms, on the other hand, represent the actual content of a lesson, and used in conjunction with the other classes of algorithms, provide a logical and systematic methodology for the instructional designer.

REFERENCES

Bunderson, C. V. - The Computer and Instructional Design. In W. H. Holtzman (Ed.) Computer-Assisted Instruction, Testing, and Guidance. New York: Harper & Row, 1970.

Coscarelli, W. C. - Algorithmization in Instruction. Educational Technology, Feb. 1978, 18, 18-21.

Davies, I. K. - Competency Based Learning: Technology, Management, and Design. New York: McGraw-Hill, 1973

Gagne, R. M. - The Conditions of Learning, New York: Holt, Rinehart and Winston, 1977.

Gagne, R. M. and Briggs, L. J. - Principles of Instructional Design, New York: Holt, Rinehart and Winston, 1979.

Gerlach, V. S., Reiser, R. A., and Brecke, F. H. - Algorithms in Education. Educational Technology, Oct. 1977, 17, 14-18.

Kopstein, F. F. - What Is Algorithmization of Instruction? Educational Technology. Oct. 1974, 14, 13-19.

Landa, L. - Cybernetics Methods in Education. Educational Technology, Oct. 1977, 17, 7-13

Landa, L. - Algorithmization in Learning and Instruction. Englewood Cliffs, N.J.: Educational Technology Publications, 1974.

Merrill, P. F. - Algorithmic Organization in Teaching and Learning: Literature and Research in the USA. Improving Human Performance: A Research Quarterly, 1977, 6, 93-112.

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APPLICATION OF SOFTWARE DESIGN METHODOLOGY FOR SMALL MAINTENANCE TRAINERS

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PURPOSE

The prime purpose of Simulated Avionics Maintenance Trainer (SAMT) Common Core Program was, and still is, to design and develop the hardware and software designs and techniques which will allow us to build and deliver training equipment that is cost effective and very responsive to short delivery schedule restrictions. Common hardware and software modules are to be developed which will supply our company with a menu of technology available for the SAMTS of the near future. It is anticipated that this will be a continuing effort so that we can update our capabilities as new requirements come over the horizon.

BACKGROUND

Before committing to an approach to the SAMT Common Core, Grumman carefully studied the future requirements for maintenance trainers of the near future by evaluating future procurements and doing extensive in-house studies. Based on our knowledge of several possible trainers, we ascertained that the following characteristics would be included in new maintenance trainers:

- Multi-Student station operation
- Incorporation of many of the Computer Based Education (CBE) features
- Controlling a variety of visual projection devices
- Controlling various types of interactive CRT terminals
- Capability of user to modify lessons readily without requiring programming knowledge.

Based on the preceding criteria, the decision was made to use the emerging 16 bit microprocessor for all Common Core development effort because of the following characteristics:

- Ability to directly address large size memory (1 Megbyte and up) which is required for CBE applications
- Readily adaptable to multiprocessing, the requirement imposed by multi-student station operation.

Additionally, this size of microcomputer system fit in very well with the capabilities we had developed on other size microcomputers and minicomputers.

A survey was made of the available 16 bit microprocessors; those suppliers that were given serious consideration are shown in Table 1.

LONG RANGE GOALS

This program has as its goal the generation of software modules, having maximum portability, for a family of microcomputers and minicomputers which, together with a group of circuit design modules, will allow a "mix and match" selection to cover most simulated electronics maintenance trainer requirements.

Specific long range goals include:

- 16 bit microprocessor based instructor/operator station to interface with multi-student stations
- Software module to control a 120 image, or greater, microfiche/audio system with random access
- Software module to control a random access video system
- Software module to handle dumb and smart terminals
- Software module to handle standard peripherals
- Software module to handle student scoring and evaluation
- Software module(s) to demonstrate CAI capabilities
- Signal generation and display using software and hardware modules developed from on-going projects and development of new techniques
- Design of hardware modules to represent typical system and support equipment indicators and controls including:
  - Single and multiposition switches
  - Analog inputs (pots, control stick, frequency selection, etc.)
  - Digital displays

TABLE 1 16 BIT MICROPROCESSOR CHARACTERISTICS

MFG/CHIP	AVAILABILITY	SECOND SOURCE	DESCRIPTION	STATUS	SPECIFICATION	SUPPORT	
						HARDWARE	SOFTWARE
DATA GENERAL MN601 (MICRO NOVA)	NOW	NONE	IMPLEMENTATION OF NOVA 3, INCLUDING MEMORY AND SIMILAR I/O.	LOWER RISK CHOICE FROM STANDPOINT OF SUPPORT SOFTWARE, HOWEVER PARTS REMAIN RELATIVELY EXPENSIVE. NO DUPLICATION FROM OTHER MFG.	EXECUTES NOVA 3 INSTRUCTIONS AND APPROXIMATES NOVA 3 I/O. MAX OF 32KB MEMORY.	CAN USE REGULAR NOVA 3 MINICOMPUTER AS HOST FOR SOFTWARE DEVELOPMENT OR MICRO NOVA. HAVE PACKAGED I/O, AND MEMORY BOARDS.	WIDE RANGE OF SOFTWARE EXISTS. DOS, RTOS, FORTRAN IV, BASIC, ETC.
FAIRCHILD 9440/9445	NOW 9440 1979 9445	NONE	CIRCUITRY IMPLEMENTS NOVA 1200 AND NOVA 3 MINI COMPUTERS.	DATA GENERAL HAS INSTITUTED LEGAL ACTION AGAINST FAIRCHILD FOR HARDWARE AND SOFTWARE INFRINGEMENTS. DG WON A SIMILAR CASE AGAINST DIGITAL COMPUTER CONTROLS SEVERAL YEARS AGO.	CURRENT 9440 EXECUTES ALL INSTRUCTIONS OF OLDER NOVA 1200. PLANNED 9445 WILL EXECUTE INSTRUCTIONS OF NOVA 3.	EVALUATION BOARD: SPARK 16 PC BOARD MAY BE USED AS OEM BOARD OR STAND ALONE COMPUTER. INCLUDES CPU, 4K RAM, 2K PROM INCL. MONITOR, MEMORY CONTROL WITH DMA, LOGIC FOR SERIAL PORT. REQUIRES TTY OR CRT.	SOFTWARE AVAILABLE THROUGH BASIC AND MACRO-ASSEMBLER. IN NEXT SIX MONTHS, DOS, IDOS, REALTIME EXEC, FORTRAN, AND PASCAL.
INTEL 8086	NOW	MOSTEK	INTEL OBJECTIVE IS TO OFFER MACHINE THAT MATCHES PERFORMANCE OF MID-RANGE MINI-COMPUTERS, BUT RETAINS SOME UPWARD COMPATIBILITY WITH 8080/8085.	USER BENEFITS FROM COMPANY'S POSITION AS RELIABLE, AGRESSIVE SUPPLIER WITH BROAD BASE OF SUPPORT, I.E., COMPATIBLE MEMORIES, BUS DRIVES, SUPPORT CHIPS, AND DEVELOPMENT TOOLS.	CPU CAN REACH 1 MEGABYTE MEMORY SPACE. MULTIBUS ARRANGEMENT IS READILY ADAPTABLE TO MULTIPROCESSING.	INTELLEC MODEL 230 DEVELOPMENT SYSTEM ICE 86 FOR SOFTWARE AND HARDWARE DEVELOPMENT. SDK-86 SINGLE BOARD MC.	MODEL 230 ISIS-II DOS, ASM-86 ASSEMBLER, CONV-86 (8080 TO 8086 TRANSLATOR) PL/M-86 COMPILER, ICE-86 SOFTWARE SDK-86 FIRMWARE MONITOR/DEBUGGER.
MOTOROLA 68000	1979 AVAILABILITY INDEFINITE	NONE – POSSIBLY SAME FIRMS THAT SECOND SOURCE 68000	MOST AMBITIOUS NMOS μP DESIGN PRESENTED, HAS 32 BIT WIDE CPU REGISTERS, DATA PATHS AND ALU; OUTPUTS 24 BIT ADDRESS TO DIRECTLY REACH 8 MEG.	SUPPLIER PUSHING STATE OF ART BY PACKING 75000 ACTIVE ELEMENTS ON A 64 PIN PACKAGE.	LARGE COMPUTER ARCHITECTURE, 24 BIT TOTAL ADDRESS LINES TO ADDRESS 16M LOCATIONS. 16 BIT WIDE EXTERNAL DATA BUS EXPANDS TO 32 BIT INTERNAL BUS, (8) 32 BIT DATA REGISTERS, (8) 32 BIT ADDRESS REGISTERS, ALU IS 32 BITS WIDE.	MOTOROLA PLANS TO USE EXORCISER DEVELOPMENT SYSTEM TO RUN DEVELOPMENT SOFTWARE AND CONTROL PROTOTYPES VIA ICE. ABOVE AREAS ARE VAGUE AT MOMENT	PROBABLY DEVELOPING CROSS ASSEMBLER FOR 68000 THAT WILL RUN ON EXORCISER STATION.

TABLE 1 16 BIT MICROPROCESSOR CHARACTERISTICS (Cont)

MFG/CHIP	AVAILABILITY	SECOND SOURCE	DESCRIPTION	STATUS	SPECIFICATION	SUPPORT	
						HARDWARE	SOFTWARE
TEXAS INSTRUMENTS 9900-9980/81 SBP 9900A	NOW FOR ALL THREE MODELS	AMI-9900 AND 9980/81 SMC – 9980 NONE FOR SBP 9900A	EXTREME EXAMPLES OF MEMORY TO MEMORY ARCHITECTURE (INCLUDING CPU REGISTERS). MP SUITABLE FOR MULTIPROCESSING AND RAPID CONTEXT SWITCHING UPON INTERRUPT OR SUBROUTINE CALL. DEVICES ARE PART OF BROAD LINE.	TI HAS INVESTED HEAVILY IN THIS FAMILY, BUT HAS NOT GAINED THE LEADING MARKET. 1979 PROBABLY CRITICAL YEAR FOR 9900 WITH ADVENT OF OTHER 16 BIT μC.	UNIFIED MEMORY ARCHITECTURE IN WHICH WORKSPACE POINTER IN CPU DEFINES WHICH 32 BYTE SECTION OF RAM WILL BE USED FOR CPU WORKING REGISTERS; 64 PIN PACKAGE CAN ACCESS 32K, 16 BIT WORDS EXTERNALLY FOR 9900; 9980, AND 9981 IN 40 PIN DIP AND CAN ONLY ACCESS 8K 16 BIT WORDS.	DEVELOPMENT SYSTEM: AMPL 990 MINI BASED STATION WITH CRT, FLOPPY OR HARD DISC; SUPPORTS MULTIPLE USERS. EMULATOR BOARDS TO INTERFACE TO USER PROTOTYPES; BOARD LEVEL ASSEMBLIES.	FOR AMPL: HIGHER LEVEL LANGUAGES INCLUDE C030L, FORTRAN, BASIC PASCAL AND AMPL. FROM PROGRAMMING AND ICE. TIME-SHARING AVAILABLE ON GE, NCSS AND TYMSHARE.
ZILOG Z8000	BEST GUESS IS 2ND QUARTER FOR Z8000; SECOND HALF 1979 FOR MEMORY MANAGEMENT CHIP.	AMD, LICENSED	HAS ARCHITECTURE OF LARGE MINI (PDP-11) AND MAIN FRAME (IBM 360/370) MACHINES. COMES IN 40 PIN PACKAGE FOR 64K MEMORY AND 48 PIN PACKAGE FOR ADDRESSING UP TO 8M BYTE MEMORY. CLAIMED TO OUTPERFORM PDP-11/45.	AMBITIOUS CHIP THAT ZILOG HAS HAD DIFFICULTY IN PRODUCING. DELAY OF ALMOST ONE YEAR. WITH THIS MP, SUPPLIER IS DEPARTING FROM 8080 ARCHITECTURE. Z8000 WILL HAVE OWN LINE OF I/O SUPPORT CHIPS.	DIRECTLY ADDRESSABLE MEMORY SPACE OCCUPIES 64K LOCATIONS BUT CAN BE EXPANDED TO 8M LOCATION BY SEGMENT SELECT. 100 BASIC INSTRUCTIONS WITH 410 COMBINATIONS. EIGHT LARGE COMPUTER STYLE ADDRESSING MODES PLUS UNUSUALLY LARGE REPERTOIRE OF BLOCK AND STRING OPERATIONS. READILY ADAPTABLE TO MULTIPROCESSOR OPERATION. REQUIRES SEPARATE MEMORY MANAGEMENT UNIT FOR 8M MEMORY.	ZDS Z80 BASED DEVELOPMENT SEPTEMS WILL RUN Z8000 CROSS SOFTWARE. Z8000 SYSTEM ANALYZER WILL PERMIT ZDS TO COMMUNICATE WITH Z8000 PROTOTYPE.	ZILOG EXPECTS TO SUPPORT Z8000 WITH TRANSLATORS FOR PLZ, BASIC, COBAL, AND FORTRAN. THESE WILL PERMIT CONVERSION OF Z80 CODE TO Z8000 CODE SINCE Z8000 SET IS SUPERSET OF Z80.

- Counters (electrical, mechanical)
- Analog outputs (meters)
- Audio output

- Software module to handle all input/output operations of the simulator
- Software module to handle all input/output operations of the simulator
- Software module for initialization of the system
- Develop maintenance algorithm and software module for a demonstration trainer which can be used with minor modification for a wide range of trainers.

INITIAL OBJECTIVES

The guidelines established for the initial phases of this effort were keyed to a straight-forward implementation of the target concepts and methodologies. This approach limited the ambiguities in the analysis and evaluation of results. It also provided for a cost effective and expeditous production of a device to meet near term requirements. Such a device is shown in Figure 1.

Specific goals are as follows:

- Develop a "sample" student station using a 16 bit microprocessor and typical aircraft (A/C) system controls
- Interface to a display device (video disc or microfiche) at the student station
- Interface student station computer to interactive terminal
- Develop a very limited maintenance trainer program to demonstrate capability
- Determine requirements for an instructor station capable of handling multiple student stations using the same 16 bit microcomputer
- Determine impact on SAMT software of a portable language for computer aided instruction.

SAMT COMMON CORE DESIGN

HARDWARE

As stated previously, it is our intent to stress modularity in the design of the SAMT Common Core, since this is the technique that Grumman feels offers the most cost effective approach for its development efforts for maintenance trainers.

In general, trainers consist of the System Simulation and the Computing System. Most modern computers are designed and built in a modular fashion so that the unit can be customized readily to the user's requirements. This is especially true of minicomputers and microcomputers, since these configurations are sized for the "smaller"

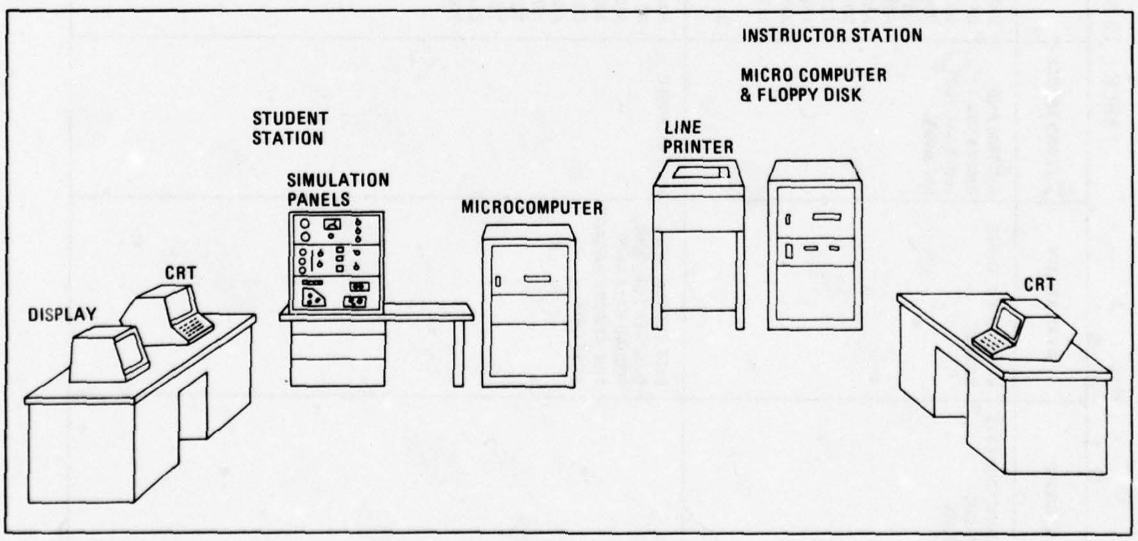


Fig. 1 SAMT Common Core

user where a myriad of different tasks are presented by the spectrum of users. Consequently, these systems must be readily adaptable, with minimum cost impact, to the various user requirements. This is accomplished with a bussed structure shown in the overview diagram of the Modular Computing System of Figure 2.

A SAMT could have any or all of the following hardware modules:

- Central Processor Unit
- N Memory Modules
- Mass Storage Unit
- Peripheral Devices
  - CRT/Keyboard
  - Teletype

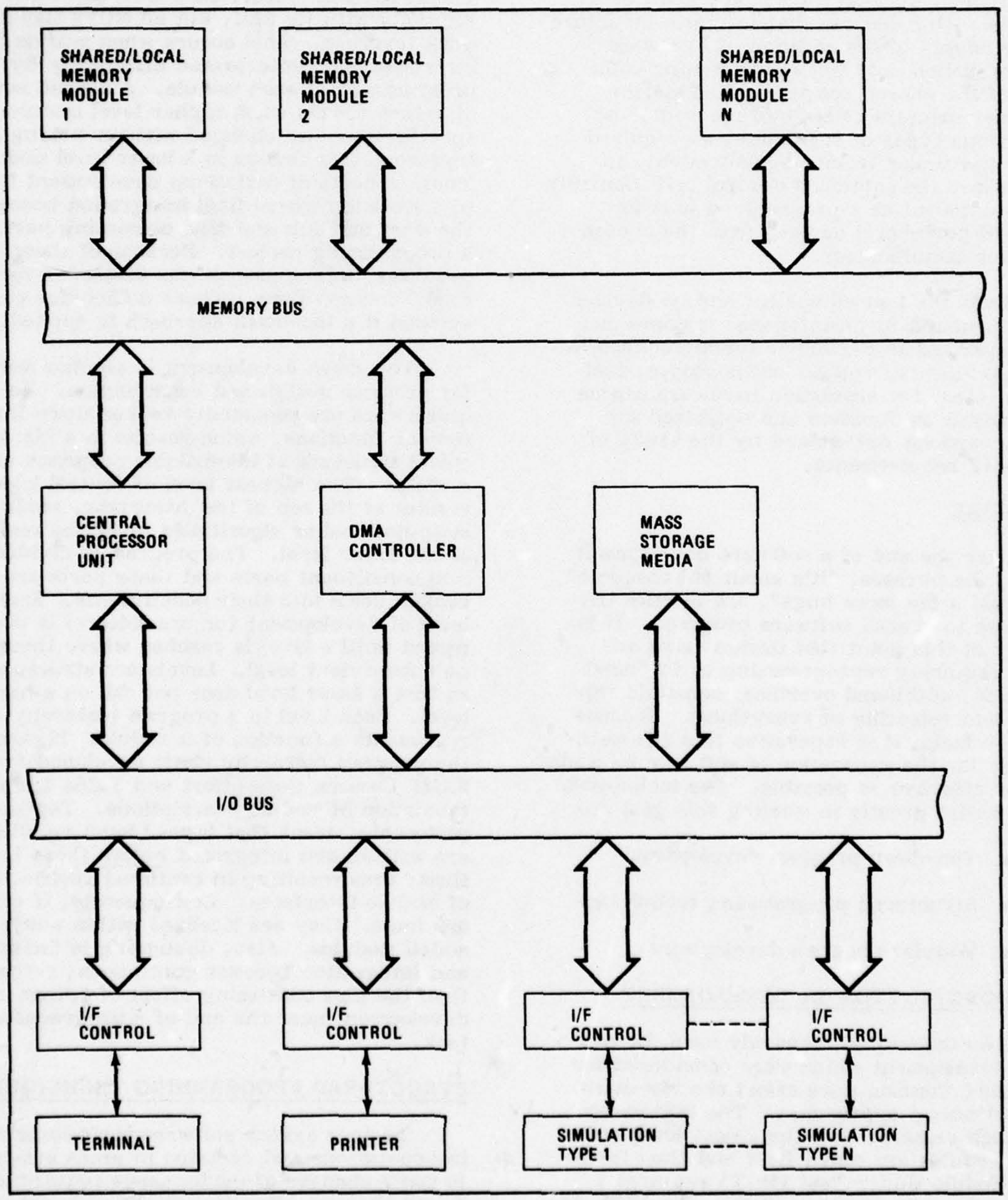


Fig. 2 Modular Computing System

- Paper Tape Punch/Reader
- Line Printer
- Character Printer

- DMA Control
- N Simulations of n devices.

A minimum configuration might be the Central Processor Unit, (1) Memory Module, and terminal, such as a CRT/Keyboard or a Teletype. One can see that the buss structure readily adapts to the addition of hardware modules limited only to the addressing capability of the chosen computer, line and/or character printers, mass storage media and the various types of simulation, as required by the particular trainer specification. In most cases, the Interface Control (I/F Control) can be obtained as a predesigned unit for standard peripheral devices from the chosen computer manufacturer.

Since the test equipment and/or devices to be simulated for maintenance trainers can be categorized to particular functions such as switches, lights, meters, oscilloscopes, test points, etc., the simulation hardware can be modularized by function and optimized for module capacity determined by the study of the SAMT requirements.

SOFTWARE

Near the end of a software development effort, the phrases, "it's about 90% complete", and "just a few more bugs", are usually the response to overall software progress. It is usually at this point that design flaws are found requiring reprogramming to fit "new" things in, additional overtime, schedule slippage, and retesting of everything. Because of these facts, it is imperative that the methodology for the generation of software be made as cost effective as possible. The techniques which assist greatly in meeting this goal are:

- Top-down program development
- Structured programming techniques
- Modular program development.

TOP-DOWN/BOTTOM-UP DEVELOPMENT

Two techniques commonly used for program development which were considered for the SAMT Common Core effort are top-down and bottom-up approaches. The bottom-up approach requires that the lowest level program modules are coded first and then tested. Each Module Under Test (MUT) requires a Special Exercise Routine (SER). The SER permits transmission of test data to the MUT and receives output from it so that intermediate results can be verified as being correct. Since SERs are not modules of the final program, they represent additional time and resources spent on an undeliverable item. At first glance, bottom-up appears to be a pyramid building scheme, whereby a level of confidence is established in the correctness of each MUT prior to going on to the next highest module. Theoretically, the total integration of all modules should be a minimal effort leading to the successful completion of the project. However, there are several reasons why this situation seldom occurs. First, each MUT can work correctly with its SER, but all MUTs may not work together. This occurs when module interfaces were interpreted differently by the programmers of each module. A second source of errors occurs when higher level module specifications are changed without making a corresponding change in a lower level module. These aspects of bottom-up development lead to a situation where final integration becomes the most difficult and time consuming part of a programming project. Because of these problems, this approach was discarded for the SAMT Common Core. These difficulties can be avoided if a top-down approach is applied.

Top-down development is another method for program design and construction. Requirements are repeatedly broken down into simpler functions, which results in a hierarchical structure of identifiable programs and modules. The highest level of control logic resides at the top of the hierarchy, while the computational or algorithmic functions reside at the lower level. The program is divided into constituent parts and these parts are broken down into their constituents. Each level of development (or breakdown) is continued until a level is reached where there is no subservient level. Levels are structured so that a lower level does not call on a higher level. Each level in a program hierarchy chart represents a function of a module. Figure 3 is the program hierarchy chart developed for the SAMT Common Core effort and Table 2 is a tabulation of module descriptions. Top-down philosophy means that higher level modules are written and integrated before those below them, thus resulting in continual verification of module interfaces. Consequently, if errors are found, they are localized within newly added modules. Also, debugging is facilitated and integration becomes continuous, rather than the time consuming effort of bottom-up development near the end of a programming task.

STRUCTURED PROGRAMMING TECHNIQUES

Trainer system software implements training operations and doctrine in areas susceptible to many changes of performance requirements. These changes often impact the software and need expeditious implementation. This demands that trainer system software be de-

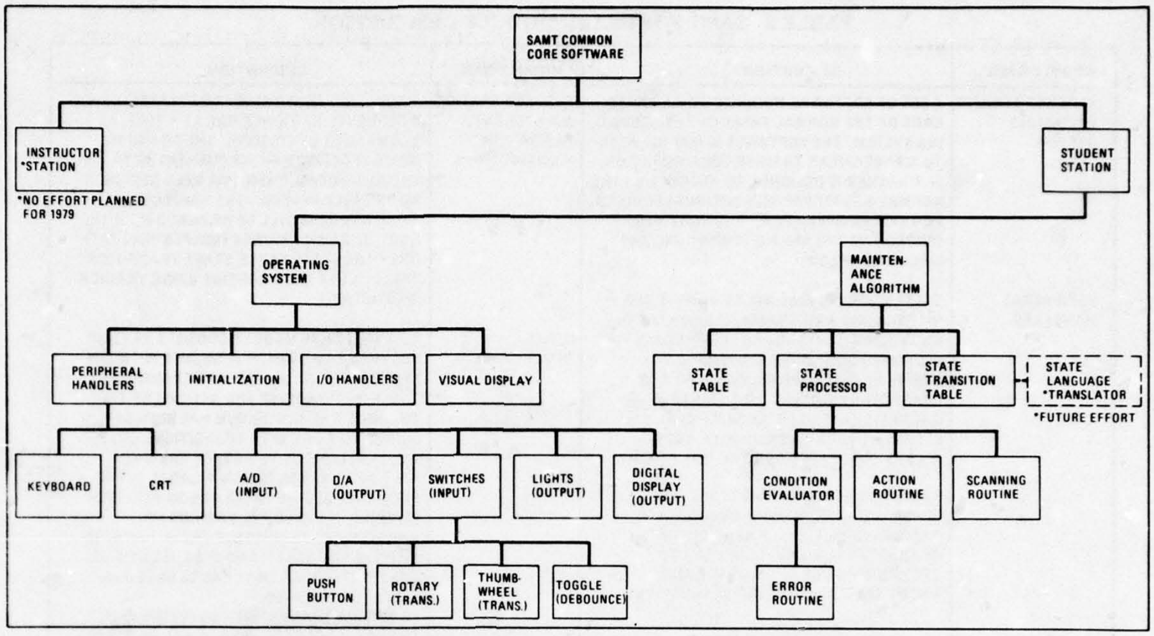


Fig. 3 SAMT Common Core Hierarchy Chart

signed to facilitate efficient change. The application of structured programming techniques to the SAMT Common Core helped meet this requirement.

Structured programming is a methodology for writing programs which are reliable, readable, maintainable, and easily modifiable by other programmers. The constructs used are all structured, having a single entry and exit point. The five basic structures (see Figure 4) used for decomposing any module are: the SEQUENCE of operations (assignment, add, ...), IF THEN OR ELSE, DO WHILE, DO UNTIL and CASE. The purpose of these structures is to produce correct programs; i.e., it actually does what it is supposed to do. By using the basic structures, the logic flow of a module will be from top to bottom. This forward direction of program logic makes a program easier to read when it must be modified. Since modules represent functions having only a single entry and exit point they represent a pattern of linear reasoning which by itself assists in writing correct code.

MODULAR PROGRAM DEVELOPMENT

The terms Module and Program have been used without definition. An accepted definition of Module is that it is a collection of logically related code having a single entry and exit point that performs a single function. Characteristics of a Module are:

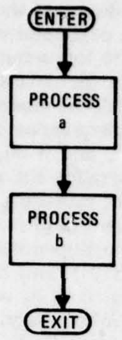
- The cause of errors can be easily isolated to a single pair of modules.
- Program development is expedited since it is easier to code, test, and debug several simple modules than one complex program.
- Modularity permits the partitioning of the program development effort into parallel tasks.
- The ability to replace modules which perform inefficiently.
- Each module should have a descriptive name, as well as a sequence number, so that the module can be uniquely identified for configuration control purposes.
- Increased comprehensibility since it is possible to study the program one module at a time.
- Independently compiled modules reduce overall compilation time and resource usage.
- Modules should not exceed more than 200 executable statements.

The Maintenance Algorithm developed for the SAMT Common Core is trainer independent; i.e., only the lesson sequences change. Modularizing the Maintenance Algorithm enabled us to establish single point access to the Operating System (O/S). This

TABLE 2 SAMT SOFTWARE MODULE DESCRIPTION

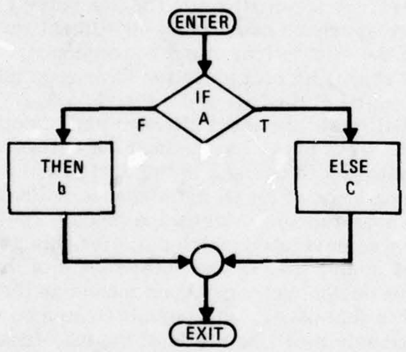
MODULE NAME	DESCRIPTION	MODULE NAME	DESCRIPTION
STUDENT STATION OPERATING SYSTEM	A SET OF SOFTWARE MODULES WHICH TAKES CARE OF THE NORMAL TASKS OF THE COMPUTING SYSTEM. THE SOFTWARE IS NOT RELATED TO A PARTICULAR TRAINER CONFIGURATION, BUT RATHER IS DESIGNED TO ACCOMPLISH THE NORMAL HOUSEKEEPING ROUTINES REQUIRED FOR SYSTEM OPERATION. THE ROUTINES REQUIRED FOR THE SAMT COMMON CORE ARE DISCUSSED BELOW.	STUDENT STATION MAINTENANCE ALGORITHM (CONTINUED)	VISUALIZED AS SEQUENCES OF STATES, DOING A SEQUENCE OF THINGS ONE AT A TIME, AS COMMANDED BY ITS USER. THE TRAINER'S STATE IS DEFINED BY ITS CURRENT ACTIVITY. THE ALGORITHM, THEN, HAS BEEN DESIGNED TO BE TABLE DRIVEN. THE VARIOUS SOFTWARE MODULES WILL BE DESIGNED WITH THE GOAL OF BEING TRAINER INDEPENDENT WITH ONLY THE STATE TABLE, STATE TRANSITION TABLE, AND ERROR ROUTINE BEING TRAINER DEPENDENT.
PERIPHERAL HANDLERS	THESE MODULES WILL ACCOMMODATE THE INTERFACING AND TRANSFER OF DATA TO AND FROM THE STANDARD PERIPHERALS USED WITH COMPUTING SYSTEMS. CATEGORIES OF INSTRUMENTS HANDLED ARE CHARACTER PRINTERS, LINE PRINTERS, MAGNETIC TAPE UNITS AND CRT/KEYBOARDS. THE CRT/KBD MODULE ONLY WILL BE DEVELOPED FOR THE 1979 EFFORT. TASKS INCLUDE USING THE INDUSTRY STANDARD RS232, HANDLE SERIAL DATA TRANSMISSION, ECHO OF KBD GENERATED CHARACTER THROUGH COMPUTER TO CRT, DECODING OF CHARACTERS AND MNEMONICS FOR COMMAND GENERATION.	STATE PROCESSOR	THIS SOFTWARE MODULE CONSISTS OF FOUR SUB-PROGRAMS, WHICH TOGETHER WITH THE STATE TABLE AND THE STATE TRANSITION TABLE (STT) PROCESS THE ACTIONS OF THE TRAINER. THE ALGORITHM HAS BEEN DESIGNED TO WORK WITH TRANSITIONS ONLY, WHICH ALLOWS US TO REDUCE THE DATA BASE REQUIREMENTS SIGNIFICANTLY. THE FOUR SUBROUTINE TASKS ARE AS FOLLOWS: **SCANNING** – CALLS THE VARIOUS I/O HANDLERS, DETERMINES IF THERE HAS BEEN A CHANGE OF STATE, AND IF SO, IDENTIFIES THE INPUT DEVICE THAT HAS CHANGED AND POSTS THE CHANGES. **CONDITION EVALUATOR** – DETERMINES IF THE CORRECT STATE CHANGE HAS OCCURRED BY A COMPARISON TO THE INDEXED STEP OF THE STT. DEPENDING ON THE RESULTS OF THE EVALUATION, EITHER OF THE FOLLOWING SUBPROGRAMS IS CALLED BY THE EVALUATOR. **ACTION** – ACTIVATES THE CORRECT DISPLAY, LAMP, METER OR ANY TRAINER REACTION TO THE STUDENT CORRECT ACTION BY CALLING THE REQUIRED I/O HANDLER. THIS IS DONE IN CONJUNCTION WITH THE DATA STORED AT THE INDEXED STEP OF THE STT. **ERROR** – THIS ROUTINE IS CALLED AS A RESULT OF THE CONDITION EVALUATOR DETERMINATION OF AN INCORRECT ACTION ON THE PART OF THE TRAINEE. THIS SUBPROGRAM IS TRAINER PECULIAR SINCE EACH CUSTOMER WILL NO DOUBT HAVE DIFFERENT ERROR INDICATIONS TO THEIR TRAINEE. THE COMMON CORE WILL TABULATE AND EVALUATE EACH ERROR AND THROUGH GENERATIVE COMPUTER AIDED INSTRUCTION (CAI) WILL GUIDE THE STUDENT TO AN APPROPRIATE RESPONSE. IT IS ANTICIPATED THE VARIOUS INDICATIONS WILL INCLUDE ERROR LAMPS, CRT MESSAGES PLUS AUDIBLE ALARM, AND VISUAL DISPLAYS.
INITIALIZATION	THE PURPOSE OF THIS MODULE IS TO INITIALIZE THE COMPUTING SYSTEM TO THE MODE OF OPERATION REQUIRED BY THE TRAINER CONFIGURATION. TASKS INCLUDE PLACING SYSTEM INTO RESET STATE, PERIPHERAL CHIPS MODE AND COMMAND SETUP, INTERVAL TIMER MODE SETUP (AT LEAST THREE TIMERS, PARALLEL I/O PORT MODE SETUP, PROGRAMMABLE INTERRUPT CONTROLLER MODE AND COMMAND SETUP, ANALOG INPUT/OUTPUT BOARD MODE AND COMMAND SETUP, AND MULTI BUS MEMORY, PARALLEL I/O PORT, AND SERIAL CHANNEL MODE AND COMMAND SETUP.		
I/O HANDLERS	THESE SOFTWARE MODULES WILL BE USED TO TRANSFER DATA TO AND FROM THE VARIOUS HARDWARE MODULES IN THE TRAINER SYSTEM. DEVICES TO BE HANDLED INCLUDE A/D AND D/A CONVERSION, LAMP CONTROL, DIGITAL DISPLAY AND VARIOUS SWITCHES (PUSHBUTTON, ROTARY, THUMBWHEEL, TOGGLE). ROTARY AND THUMBWHEEL SWITCH TRANSITIONS AND TOGGLE SWITCH DEBOUNCE ROUTINES MUST BE INCLUDED. SWITCHES MUST BE SCANNED AT A REPETITION RATE SUFFICIENTLY FAST TO RECORD ANY CHANGES ENTERED BY THE TRAINEE. DIGITAL DISPLAYS MUST BE REFRESHED AT A RATE TO PREVENT ANY NOTICEABLE BLINKING OF THE ENERGIZED SEGMENTS.	STATE TABLE	THIS TABLE IS THE PRESENT STATUS OF THE VARIOUS SIMULATION DEVICES OF THE TRAINER AND IS TRAINER PECULIAR. WHEN THE LESSON IS STARTED, THE INITIAL STATE OF ALL OF THE DISCRETE INPUT (DIs) AND DISCRETE OUTPUTS (DOs) ARE POSTED INTO THE TABLE. AS THE LESSON IS STEPPED THROUGH, IT IS CHANGED TO REFLECT THE TRANSITIONS OF THE TRAINING DEVICE.
VISUAL DISPLAY	THE PURPOSE OF THIS MODULE IS TO INTERFACE WITH THE SELECTED VISUAL DISPLAY. NECESSARY SIGNALS WILL HAVE TO BE DEVELOPED TO DRIVE THE DISPLAY. MODIFICATION OF STRAIGHT BINARY CODE TO DISPLAY PECULIAR CODE MAY BE A REQUIREMENT.	STATE TRANSITION TABLE	THIS TABLE IS TRAINER PECULIAR IN THAT IT REFLECTS THE ACTIONS REQUIRED BY THE LESSON. FOR EACH STEP OF THE LESSON EACH TRAINEE ACTION OR ACTIONS IS STORED SUCH AS, INPUT IDENTIFICATION AND TYPE. THE CORRESPONDING TRAINER REACTION IS ALSO STORED AT THE STEP NUMBER. AS THE LESSON PROGRESSES, THIS TABLE IS STEPPED TO THE CORRESPONDING TEST NUMBER.
STUDENT STATION MAINTENANCE ALGORITHM	A GROUP OF SOFTWARE MODULES WHICH IMPLEMENTS THE TRAINING REQUIREMENTS OF THE PARTICULAR TRAINER CONFIGURATION. MAINTENANCE TRAINERS CAN BE		

A. SEQUENCE: Process a Process b

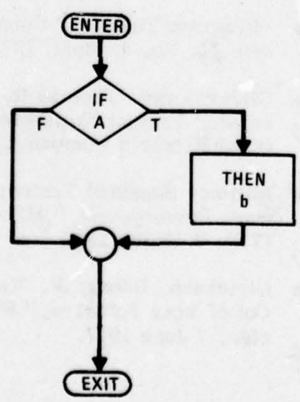


Control flows from process a to the next in sequence, process b.

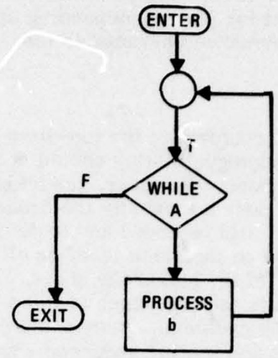
B. IF THEN ELSE: If condition A THEN b, ELSE process c.



The flow of control will return to a common point after executing either process b or c. A predicates the conditional execution. If control is to skip a process pending the condition of A, then the flow chart can be modified thusly:

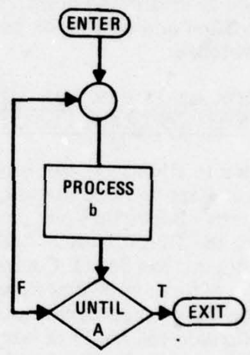


C. DO WHILE: DO WHILE condition A process b



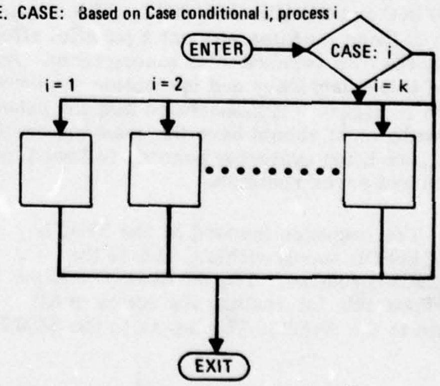
The DO WHILE structure is a loop in which the condition A is evaluated. If found to be true, then control is passed to process b and the condition A is evaluated again. If condition A is false, then control is passed out of the loop.

D. DO UNTIL: DO UNTIL condition A Process b



The DO UNTIL structure is similar to the DO WHILE – except that the test of condition A is performed after process B has executed. Thus the DO UNTIL loop will be performed once regardless of the value of condition A.

E. CASE: Based on Case conditional i, process i



Control is passed to process k based on the value of i.

Fig. 4 Control Structures

modularity approach was applied to the O/S, thus creating interface routines which can be easily substituted for others, depending upon the trainer performance characteristics.

TESTING

In order to conform to the top-down development methodology, testing should occur in the same sequence. However, the hierarchy chart (Figure 2) does not specify the order in which modules should be coded and tested; i.e., all modules on the same level or all modules within a leg of the hierarchy chart. The approach to take is the one which enables you to discover major problems as soon as possible. The development and testing sequence should consider the dependency of modules on data produced by other modules; i.e., execution order dependency.

In this approach, the functional specification of a system and the program code are verified as being correct before going to a lower level of specification. Because modules are developed from the top down, there is continued integration and testing as program modules are developed.

APPLICATION OF SOFTWARE METHODOLOGIES TO SAMT COMMON CORE FUNCTIONS

In order to illustrate our implementation of various software methodologies, an example will be given by addressing one particular module ; namely, the STATE PROCESSOR. The first step in developing the SAMT Common Core software was the definition of functions to be implemented. The short range goals mentioned previously formed the basis of our requirements. These were further refined, resulting in the hierarchy chart shown in Figure 3. Top-down development on the STATE PROCESSOR decomposed it into four modules: CONDITION EVALUATOR, ACTION ROUTINES, SCANNING ROUTINE and ERROR ROUTINE. The development of these modules was not a parallel effort due to the data dependencies among them. Analysis of this dependency and invocation sequence shown in Figure 3 demonstrated that the schedule of development should have the scanning routine first, condition evaluator second, followed by the action and error routines.

The sequence in ked by the STATE PROCESSOR starts with a CALL to the SCANNING routine. The SCANNING routine is responsible for reading the status of all inputs to the SAMT. The inputs to the SAMT are processed via the I/O HANDLER. Figure 3 shows that the dependency of the STATE PROCESSOR on data produced via the I/O HANDLER will dictate the scheduling and criticality of modules for development. The CONDITION EVALUATOR module determines whether the correct sequences of operations have been performed, and if so, causes the ACTION routine to provide the appropriate response. The ACTION module generates the outputs from SAMT and is part of the I/O HANDLER. This interdependency between the OPERATING SYSTEM and MAINTENANCE ALGORITHM is definitized by using the top-down development methodology. Critical modules can now be identified, coded, and tested, so as to insure a smoothly managed software project.

CONCLUSION

The SAMT Common Core Program, briefly discussed in this paper, being pursued at Grumman is in recognition of the growing trend toward the use of simulation for maintenance trainer applications. The computer software approach has a most significant impact on the simulation. As a consequence, careful study and consideration have gone into the selection of designs and methodologies which will yield the most efficient and effective results. This paper has defined the software methodologies to be used in the design and implementation of small maintenance trainers for the near future. A software module approach was developed which satisfies this goal. Further study, testing and refinements of the software design and techniques menus as discussed in this paper, will permit Grumman to expeditiously meet the needs of the maintenance training community with high quality, standardized and cost effective products.

REFERENCES

- "Program Testing," Computer, Volume 11, No. 4, April 1978
- Gildersleeve, Thomas R. "Data Processing Project Management," Van Nostrand Reinhold Company, 1974
- Military Standard Trainer System Software Development," MIL-STD-1644 (TD), 7 March 1979
- Ulrickson, Robert W. "Getting the Bugs Out of Your Software," Electronic Design, 7 June 1977.

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A GENERALIZED SOFTWARE DEVELOPMENT AND SUPPORT ENVIRONMENT FOR THE A-6E WEAPON SYSTEM TRAINER (A6E-WST)

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Grumman Aerospace Corporation

INTRODUCTION

As the role of software becomes an increasing, if not overwhelming, factor in the complexity, cost, and schedule of training devices, maintaining and assuring management visibility and control have become a decided challenge. As change and growth become a way of life for large software systems, this challenge extends throughout the life cycle of the device, encompassing the support phase as well. The software development environment for the A-6E Weapon System Trainer (A6E-WST) was spawned to meet this challenge.

It is the intent of this paper to provide an overview of the environment and tools created for the development and support of the software for the A6E-WST. The principal objective was to produce an environment which minimized the cost and schedule for the development of the device software while providing substantial visibility, traceability, and manageability for the software product. Secondary objectives were to; 1) reduce the cost and improve the value of documentation, 2) provide a generalized platform for technological growth, and 3) provide for extension to other and future training devices.

The software development environment is an integrated collection of software tools, management systems, and procedures, which are operational on Interdata 8/32 and IBM 370/168 mainframes. Automation of functional capabilities for simplicity of use and reliability of performance has been a keystone concept during the development of this environment. Accordingly, in addition to the development of proprietary software, maximum utilization is made of off-the-shelf software packages from such companies as Infodata Systems, Cincom Systems, and Applied Data Research Inc. This ensemble of resources, software tools, management systems, and computing systems as a collection, is referred to as the Grumman Software Development Facility (SDF).

BACKGROUND OF REQUIREMENT

A brief review of the A6E-WST will provide some insight to the requirements imposed on the design of the SDF. The A6E-WST, the first of which was delivered to NAS Oceana, Virginia, represents one of the first of the new breed of trainers (Multi-Computer, Software Intense) being introduced into the Navy inventory.

The Navy contracted with the Grumman Aerospace Corporation to design, develop, and build two A-6E Weapon System Trainers to provide a practical and economical solution to training Intruder pilots and bombardier-navigators (B/N) to work together as a team. The trainee station (Figure 1) is an exact replica of an A-6E cockpit mounted on a hydraulically controlled 6-degree-of-freedom motion system, and simulates normal and emergency flight conditions in all modes of weapon system operation. Procedures for preflight taxi, take-off (carrier and field), enroute, attack, approach, landing (carrier and field) and post flight can be performed under normal, degraded and emergency conditions. Modeling for high and low speed flight, high "G" maneuvers, high angles of attack, stalls, spins, post stall gyrations, and buffet onset have all been integrated to provide realistic flying qualities for pilot indoctrination and proficiency training. Training is initiated and controlled from the instructor station which contains the controls and displays used to set up and control the training scenario, introduce malfunctions (manual and automatic), automatically monitor training procedures, and evaluate student performance. To aid the instructor with these tasks, the station includes two consoles with four interactive CRT displays controlled by two DEC PDP-11/05 computers.

Four Interdata 8/32 computers handle the basic real-time simulation software; two for flight, one for tactics, and one for the Digital Radar Land Mass Simulator (DRLMS). The simulation computers are supported with the usual complement of disc and tape drives, teletypes, printers, and digital conversion equipment. In addition, the simulation complex contains over 30 racks of electronics, which handle such functions as the simulation of ECM displays, and the terrain occulting of both moving targets and ECM threats. The DRLMS provides a real-time simulation of the functional, operational and performance characteristics of the AN/APQ-156 radar, including high resolution, low altitude imagery and video for low altitude terrain clearance. The complex of simulation computers also includes the on-board IBM 4Pi computer with its associated tactical program.

In addition to functioning as a full mission WST, the A6E-WST is capable of being used as an operational flight trainer (OFT) or tactics trainer. When used as an OFT, pilots can be trained separately in aircraft

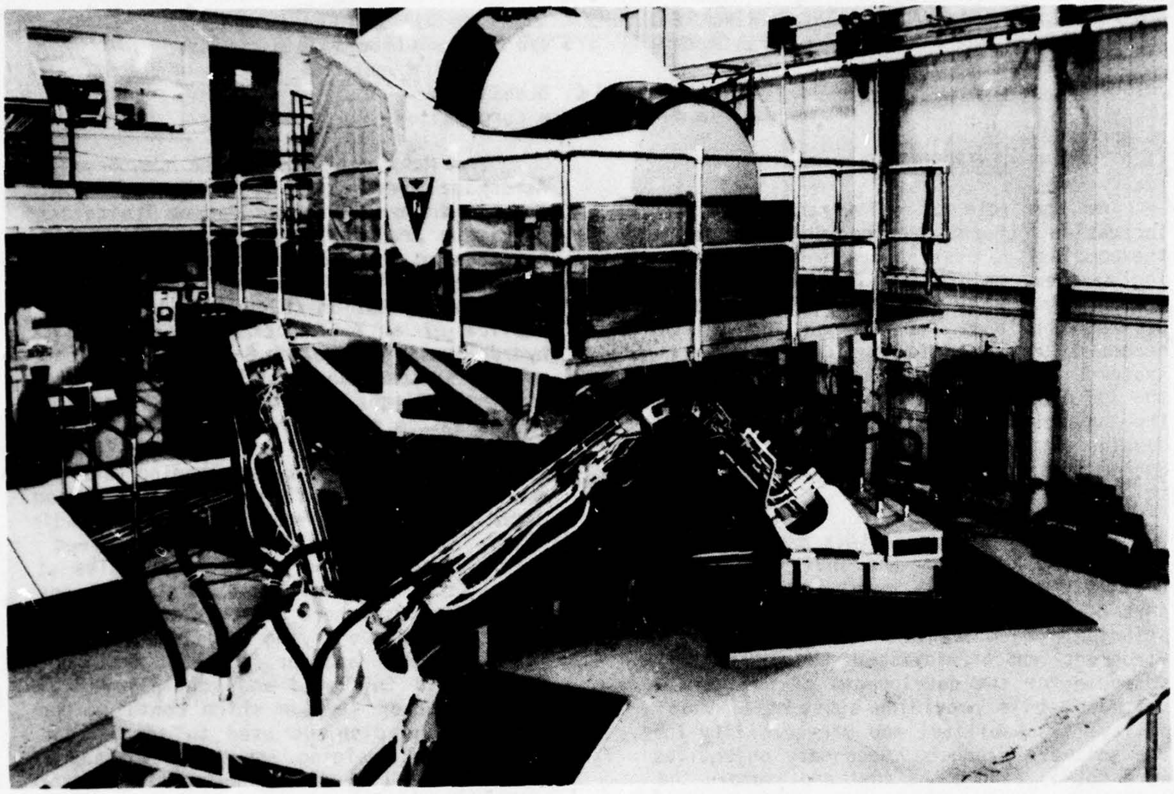

FIGURE 1 A6E WST

control, instrument procedures, engine control, communications, and normal and emergency procedures. As a tactics trainer, B/N's receive separate training in the use of the attack navigation system including radar scope interpretation, communications, navigation, and normal and emergency procedures. The FULL MISSION, TACTICS INDEPENDENT and FLIGHT INDEPENDENT Modes are three of eight modes of operaton of the trainer. The trainer is capable of using the DYNAMIC REPLAY Mode to record and play back a complete training scenario on the entire trainer in all three modes for a 2-1/2 hour mission. The WST provides the ability to play back pre-recorded DEMONSTRATION MANEUVERS, and enables the instructor to program an entire mission scenario (including pre-programmed time dependent malfunctions and pre-programmed target or threat maneuvers) in PLAN mode. Graphic pages which are saved during a mission together with the recording of events and specific parameters are plotted in the PRINT-PLOT Mode. The last mode of operation is the automated device testing capability referred to as DAILY READINESS TEST Mode (DRED) which provides an exhaustive and automatic readiness test of all sub-systems including the simulation computers, DRLMS, and 4Pi computer.

The simulation of the A-6E aircraft systems imposed a substantial design requirement on software as can be seen from the numbers of flight and tactics models in Figures 2a and 2b. Although the principal weapon system models alone were an imposing software requirement, the overwhelming driver of the software challenge proved to be the instructor aids and real-time graphics interface. As the design has evolved, the major software subsystems (Figure 3) account for over 80% of the lines of source code written. In more quantitative terms, the 41 flight models and 19 tactics models which account for 20% of the software, have been programmed to provide the proper simulation behavior in all modes of operation and in the submodes of run, freeze, reset, and advance reset. In addition, the models have been programmed to maintain the proper simulation response to over 650 malfunctions, individually or in any combination. Over 400 distinct graphic pages can be displayed at the instructor consoles. In terms of software, the flight, tactics and software subsystems represent in excess of 1,000 software modules, communicating via 8,600 mnemonics in the data base with over 3,000 interface signals between the trainee station and simulation complex. For each of

the four Interdata computers and each of the eight modes of operation, the various models and software subsystems are merged into unique computer task cuts (loads), of which there are 15. In summary, this represents approximately 250,000 unique lines of code distributed across four computers, eight modes, and 15 task cuts, requiring the software configuration management of over 2.0 million lines of source code per device.

For such very large and interactive software systems, current manual methodologies are no longer sufficient, and may so encumber the development process as to render that process unfeasible. The ability to obtain an impact analysis of change, and to introduce software changes rapidly and precisely, while maintaining explicit software *configuration management* control, necessitates the development of an automated environment for software development and support. The Grumman A6E-WST SDF, although conceived to support the functions of software development for the A6E-WST, was designed and developed to address the life cycle support role. Accordingly, the facility was built to provide the availability of computing resources and accessability to tools and trainer device software by one or more remote sites with both timesharing and Remote Job Entry (RJE) capabilities. The communications capability of the SDF enables maintenance personnel to support the trainer

EOM	LANDING SYSTEMS	RADAR BEACON	ADC
MOI	EPS	MOTION	PARAMETER RECORDING
TAKE-OFF & LANDING	ICE/DE-ICE	INS-FLIGHT	SURFACE FACILITIES
AFCS	UHF/ADF	FLIGHT INSTRUMENTS	DISPLAYS (VDI)
AWCLS	ICS	ECS	ARMAMENT & STORES
PRIMARY FLIGHT CONT	TACAN	WING FOLD	EVENT RECORDING
SECONDARY FLIGHT CONT	RADAR ALTIMETER	LIGHTING	AURAL CUES
HYDRAULICS	CARRIER MOTION	FIRE DETECTION	AHARS
FUEL	AERO	APC	DATA LINK
PROPULSION	AUDIO RECORDER	MALFUNCTION	IFF

4 PI - SINS ALIGN

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FIGURE 2-A FLIGHT MODELS

SEARCH RADAR	ICS
ARMAMENT & STORES	UHF
ECM RECEIVERS	SURFACE FACIL
ECM DISPENSERS	SCORING
DOPPLER RADAR	MALFUNCTIONS
INS	EVENT RECORDING
4 PI COMPUTER	VIDEO TAPE REC
EPS	ADC
LIGHTING	AHARS
	AUDIO RECORD

1262-02B

FIGURE 2-B TACTICS MODELS

EXECUTIVE/OS
DATA BASE
GRAPHICS
I/O
PLAN
DRED
PROCEDURES MONITOR
PROGRAM MISSION
DYNAMIC REPLAY
DEMO MANEUVER
EVENT/PARAMETER RECORD
LIBRARY/WCS

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FIGURE 3 SOFTWARE SUBSYSTEMS

device software in the field for system updates, changes, enhancements, additional instructor aids system improvements or other post RFT developments.

Although the overall objective of the SDF was to provide the environment to minimize development and support, costs and schedules, the design of the SDF was paced by a number of principal goals which have now become design features; namely:

o Device Availability. All software development or programmer functions which require use of only the trainer device computers have been transferred to the SDF. With the SDF available on a full time basis to support software development, the need for use of the device computers is dramatically reduced and in effect, increases the availability of the training device itself for an early dedicated commitment to integrated testing.

o Transportability. In order to maximize the cost effectiveness of providing a generalized software development and maintenance environment for present and future devices, the Grumman A6E-WST SDF was designed around a set of transportable software tools and techniques which also make possible maximum utilization of off-the-shelf software. The design criteria of minimum cost of transportability and the selection of a highly transportable generalized data management system are the keys for the transference of SDF technology to other devices with a minimum investment.

o Productivity. Overall improvement in programmer productivity was a principal goal for the SDF. Mechanisms were put in place to discourage the development of redundant software, facilitate standardization, promote auditing of as-designed vs. as-built software, encourage rapid communication of software fixes as they affect multiple subsystems, and most importantly, provide for the automation and simplification of all programmer functions from the generation of code to the creation of a task. At its present state of development the SDF provides for the programmer an environment within which 100% of all programmer functions, from code generation, through execution of the software analysis tools, to the inclusion of a change or complete task generation, are provided in an on-line interactive environment. As an example, the total automation of task generation has reduced the labor resources required by two orders of magnitude and changed schedules from 1 task in 4 months to 12 tasks in 3 weeks. In addition, tools are available to the programmer both in the SDF and on the device to expedite the evaluation of the impact of a potential change and to provide increased visibility for the tracking of problems on the device during integration.

o Software Configuration Management. Paramount to the success of a large software effort for management, technical, and performance visibility is the establishment of a software configuration management plan. The SDF utilizes a hierarchical software structure with an extent-based naming convention which allows for an absolute and unambiguous identification of any element of software and its associated data or processor output. The software configuration management scheme utilized on the SDF is the single prominent thread that maintains the continuity of identification of all source code listings, output of language processors, flow charts, object files, or load modules. In all cases, the identification is embedded within the medium itself, allowing for the automation of many validity and reasonableness checks. For example, a component of software having an older or improper release level cannot become part of a new task through any of the automated procedures unless a manual override is approved and physically implemented by the Configuration Manager.

o Accessibility. The SDF is communications oriented, and provides direct accessibility to the source code and tools regardless of the location of personnel. During development, 16 time-sharing terminals were distributed throughout three separate buildings in the Grumman Bethpage complex. The SDF communications and control software also provides for the direct transmission via RJE to the trainer sites (NAS Oceana, Virginia and NAS Whidbey Island, Washington) of source, object, or load modules, patches, tasks, general technical communication, and the output results of the tools. Although the SDF is accessible through a number of communication channels, it represents a controlled environment with a security account code structure which controls and limits access to the appropriate software structure while allowing for the progression of software modules from change and development through tests and final bonding for that account.

o Change Control And Testing. As the system evolved, it became too large to allow multiple recompilation and assembly of major components or subsystems. Such major recompilations would result in the requirement for exhaustive regression testing. At one stage of the program when the integration team was running through the acceptance test, the first four volumes of a seven volume test document required two ten-hour shifts, working seven days per week, 104 consecutive days to complete. Thus, the approach taken

was to provide mechanisms for the incremental installation of software changes and testing. This incremental build and test philosophy was supported with software change analysis tools, techniques for incremental task updates with overlays of recompiled or reassembled modules, and incremental test procedures. The fundamental philosophy for these incremental tests requires the explicit functional testing as it relates to the change and a reasonableness test of other system areas which may be impacted by the change. The SDF treats change as a way of life, one in which small changes coexist reliably with integration and one in which large change is tolerated.

o Documentation. The documentation subset of the integrated tools provides the ability to reduce the cost while enhancing the value of WS-8506 software documentation. A particular emphasis was placed upon the accuracy of the correlation between the documentation and the present as-built software. Accordingly, almost without exception, every chart, cross reference, table, flow chart, etc. is produced automatically using the most up-to-date SDF files and data bases. In those instances where the output of certain tools provided a definite enhancement of the present WS-8506 format, the 1423 DID's were modified to accommodate the new versions.

o Platform For Growth. With regard for the long range plans for the SDF and the technology it represented, the overall structure for the SDF was maintained in a very generalized sense with simplified and clearly delineated interfaces. As such, it would provide a platform for future technological growth in areas related to the support of device software for complex, software intense training devices. As an example, plans are under way to provide an experimental interface with software design and problem statement languages, such as PSL/PSA, to further augment the lifecycle support capabilities of the SDF.

RESOURCE CONFIGURATION

The IBM 370/168 computer is located in the Grumman Data Systems Headquarters building in Bethpage, and is utilized almost exclusively for management systems reporting, manipulation of technical data, and documentation support processing. The Grumman developed Test And Configuration Tracking System (TACT), a multi-data base system, is the principal management system and ties together many facets of the software development environment. This system was developed using the generalized data management system INQUIRE, a proprietary software product of Infodata Systems, Inc., Falls Church, Virginia. A hard copy terminal located in the engineering area provides on-line access to the TACT system 8 to 12 hours per day. In addition, using the RJE facilities of a nearby plant, TACT is available for batch queries or standard reports.

The Interdata complex (Figure 4) consists of dual Interdata 8/32 computers, each with 1 megabyte (MB) of memory, high speed floating point arithmetic, and writable control store options. Each central processor is configured with the following peripherals: (1) Carousel 30 Console, (1) 1,000 CPM card reader, (2) 600 LPM printers, (1) multiple density 9-track tape drive, (2) 300MB disc drives, communications interface equipment for up to 16 terminals, (1) 40MB disc drive and (1) Versatec Printer Plotter. As configured, the system has over 1,200MB of disc storage with extensive bus switching capability to permit direct access to the device computer peripherals or for changing the configuration to support backup requirements.

Although the Interdata computers are located in the Plant 31 computer room, low speed access to the system is provided by way of (16) PET 1200 CRT time-sharing terminals located on the mezzanine, manufacturing floor, and nearby engineering area trailers (Figure 5). The system is presently available by way of dial-up lines to the Training Systems headquarters in Plant 04 and the T-1 on-site operations at Oceana, Virginia. Dial-up capability will also be established at Whidbey Island, Washington, following the arrival of the second device. The principal purpose of the time-sharing terminals is to provide rapid access to the software source structure, analysis tools, and configuration control programs. In addition, these terminals can be used to transfer copies of patches, CSS procedures, software change orders and to communicate requests for listings and other messages. To handle transactions having substantial data transmittal requirements, Remote Job Entry (RJE) stations have been installed at Oceana and are planned at Whidbey Island. The RJE's (Figure 6) are Harris Model 1600's and are equipped with a CRT console, a 600 LPM line printer, and a 9-track 800-BPI tape drive. The communication link is a direct distance dial (DDD) telephone 4800 baud communication line using Bell 208-B modems. With the access capability of the time sharing terminals and the transmittal capability of the RJE, the entire computational power of the SDF is never more than a telephone call away from the device on-site (See Figure 7).

Both Interdata systems are under the OS/32 MT software operating system which

FIGURE 4 SOFTWARE DEVELOPMENT FACILITY

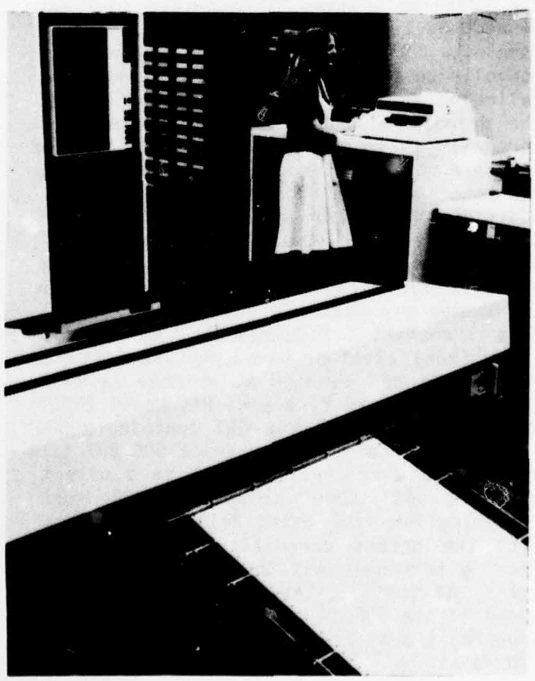

FIGURE 5 REMOTE SDF TERMINALS

FIGURE 6 SDF REMOTE JOB ENTRY

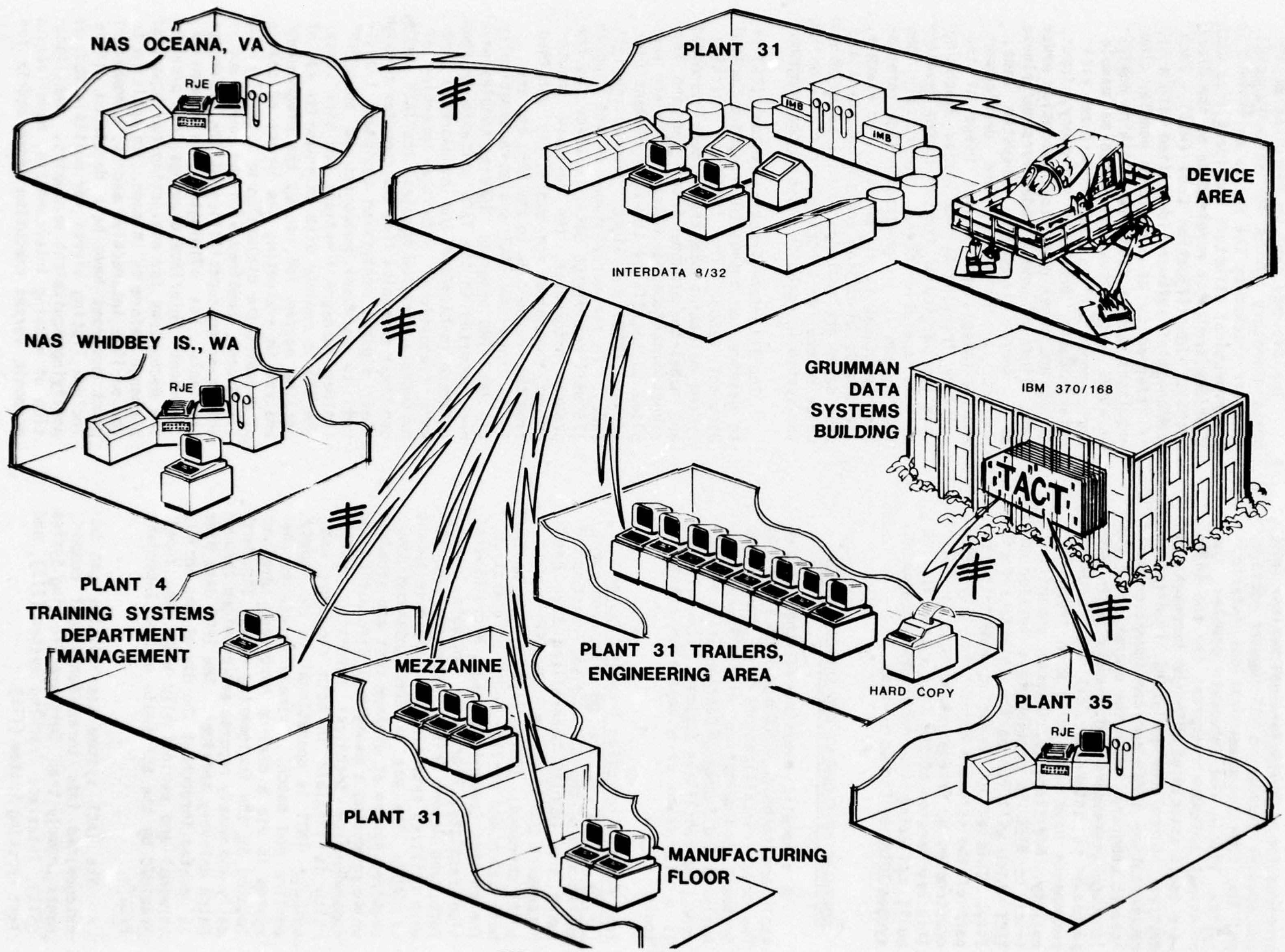

FIGURE 7 SDF COMMUNICATIONS

provides for a Multi Terminal Monitor (MTM) and spooler package, a WCS support package, and the ITAM telecommunications interface system. Within the Interdata complex, the principal software resources are the software tools associated with the language processors, source code analyzers, translators, documentation aids, and configuration management programs. With the exception of the language processors and loaders which are peculiar to Interdata, all the software components have been built with transportability. Additionally, Grumman under contract to NTEC is developing a version of TACT which will run on the Interdata facility. This effort is being undertaken as part of the software support facility being constructed by Grumman at Orlando for NTEC. This new version of the TACT system will be built utilizing the data base management system TOTAL by Cincom Systems.

SOFTWARE DEVELOPMENT AND SUPPORT TOOLS

A schematic overview of the various tools and techniques is shown in Figure 8. The major classifications are: Management Systems, Documentation Aids, Processors, Analysis And Support, Configuration Management, and Facilities Support. The following is a discussion of a selection of these tools.

Test And Configuration Tracking System (TACT). TACT is the primary management system within the SDF and was constructed using the INQUIRE Generalized Data Base Management (GDMS) system. INQUIRE is a multi-threaded, linked-list system having both batch and on-line modes of operation. The on-line Command Language, Macro Generation Facility, Procedural Language Interface, and Report Writer features of INQUIRE were utilized extensively in the development of TACT. The use of GDMS produced the required system at minimum cost and schedule while producing a management information and comprehensive technical reporting system which is flexible in both structure and output. TACT is operational in two modes, on-line and batch. Primary access to the system is via a dial-up hard-copy terminal located in the Engineering area. Standard daily and weekly reports are provided through batch delivery services. The TACT data base is updated throughout the day at the on-line terminal and periodically with tape input provided by the SDF tools on the Interdata 8/32's.

The TACT system capabilities can be categorized into three functional components, namely the: Software Tracking System (STS), Interface Tracking System (ITS), and Test Tracking System (TTS).

The STS may best be described as the parts inventory system for software. All software tracked by the SDF is maintained in a hierarchical structure and identified with a unique indicator referred to as the Hierarchical Identification Code (HID). Each component of software identified with a HID is referred to as a software module. The resultant module data base contains administrative and status data such as module name, mode utilization, core-time estimates/actuals, processor residency, input, output and local mnemonics, execution order data, lines of source code, version/release data, source language, subsystem name, project responsibility, and development and/or integration status. Usage of the Software Tracking System varies depending upon the particular trainer system development or operation phase. Accordingly, the TACT system is designed to include information pertinent to all phases. For example, the status of design and coding start and stop dates are included as well as an earned value scheme for tracking performance during the system integration phase of the program.

The Interface Tracking System (ITS) is, in essence, an automated Interface Control Document (ICD). The Interface Tracking System maintains and tracks model-to-model and model-to-hardware interfaces and key signal interface parameters which are supplied to the ITS by the Data Element Dictionary (DED) and Signal Description List (SDL). In the early stages of the program ITS utilizes design data. However, as the program progresses, the software input/-output mnemonics are explicitly obtained from the source code in the SDF, and are loaded into the TACT system automatically via the AIMS program. Special modules have been inserted in the TACT software to show software-to-hardware and hardware-to-hardware transitions. With the insertion of hardware associated modules, the TACT system can trace mnemonics from the computer through their digital conversion equipment transition to hardware mnemonics to specific trainer hardware functions and vice versa. The ITS is replete with an extensive set of on-line macros for use by the programmer/ analyst in evaluating the impact of change or pursuing the evaluation of a problem. The ITS Macros, combined with the source access and scanning capabilities at the Interdata terminals, has eliminated the expensive "bedsheet" interface drawings, and provides the mechanisms for evaluating the impact of a change before it is made. In addition to the on-line interactive macros, a number of batch programs have been developed. These include listing alerts for multiple modules modifying equivalent mnemonics, identification of missing interconnects, model versus mnemonic versus execution order matrix for

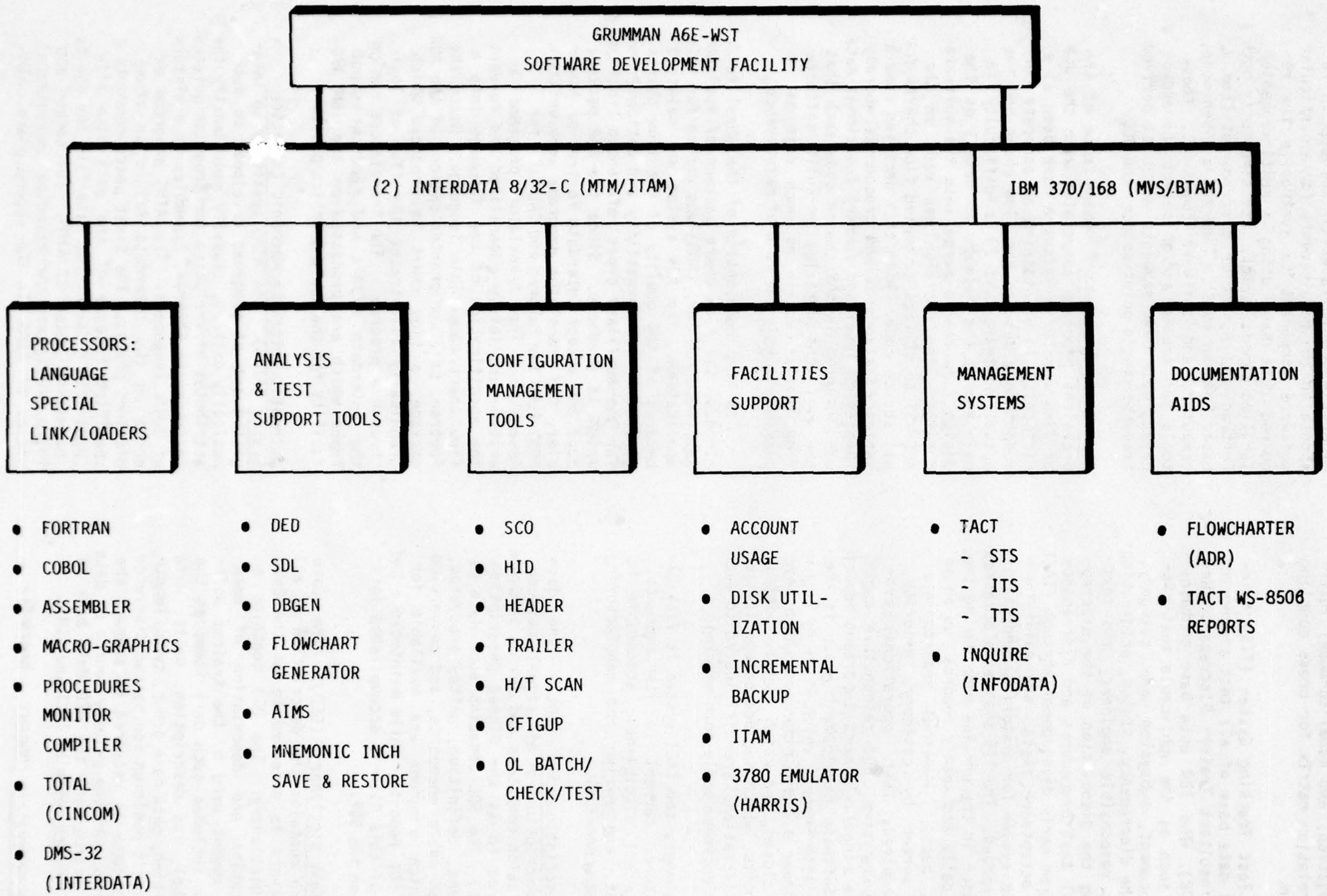

FIGURE 8 SELECTED SDF SOFTWARE TOOLS

fault isolation, and model-to-model interface correlation matrix for cross coupling evaluation.

The Test Tracking System (TTS) maintains the data base of all test procedures and the resultant Trainer Discrepancy Reports (TDR). The TDR data base contains elements such as the applicable test procedure document, subsystem name, category, text of the discrepancy, status, originating engineer, responsible engineer, and text containing the disposition of the discrepancy. All test procedures and discrepancy reports from early development through final customer acceptance tests, are maintained within the system for historical and statistical purposes. The TTS system is accessed and statused in the on-line mode during the day with daily and weekly reports run on an overnight basis. Numerous reports are produced sorted by category, priority, action required, test/ operational procedure, subysystem, and responsible engineer. The singularly most important report for the Software development group is the Responsibility Report, which lists by cognizant engineer all discrepancies which have not been closed, and which require action. These reports, which include categorization and prioritization, are distributed to each cognizant engineer early each morning.

In summary the TACT system is flexible in structure, current in its contents, usable by all disciplines, accessable to management, engineering and manufacturing areas, and economical.

Signal Description List (SDL). The data base of descriptions of all signals between the simulation computers and device hardware is referred to as the Signal Description List (SDL). The SDL contains such data as signal name, definition, units, subsystem, associated cable mnemonics, and conversion type. Batch programs are available for standard SDL reports, while maintenance and updating of this file is accomplished interactively on the SDF.

Data Element Dictionary (DED). The data base which contains the description of all data elements is referred to as the Data Element Dictionary. The DED contains an identification and description of each mnemonic symbol used by the trainer software. It includes such data items as the data symbol, its description, units, data base position, data base group, type, length, base word/bit position for packed discretes, and other data as required to support the other tools. As the primary source of data element information, the DED data base is accessed by such tools as TACT and AIMS.

Data Base Generator (DBGEN). DBGEN is a program which operates on the DED in response to the requirements for a particular software component to synthesize the required data base using a multi-segmented labelled common format. For simplicity both Fortran and Assembler programs utilize a basic Fortran shell. Thus for a given mode, computer, and software component, these tools can create and/or select the appropriate data base segments which are derived from the single point source, the DED.

Flow Chart Translator. Among some of the prevalent problems associated with the use of flow charts in software have been 1) a difficulty in maintaining an accurate correspondence between the flow chart and the actual software and 2) a difficulty in maintaining the balance of detail as the design flow charts merge into the software details. The decision was made on the A6E-WST to utilize automated flow charts for all source code. With this decision came a series of standards and procedures whereby the design level and summary functional data was inserted in the source code such that the resultant detailed as-built software flow charts contain as much data as is possible to help the role of maintenance.

To keep reinvention of the wheel to a minimum, the flow chart package of Applied Data Research Inc. (ADR) was chosen for this application. The ADR system was selected because of the quality of the flow charts generated, its versatility and options, and for the auxiliary cross referenced listings which it produces. Since the ADR package does not accept Interdata Fortran or Assembler, two translator programs were written, FORT FLOW for Fortran and CAL FLOW for Assembler. The translator programs as written are fairly generalized and convert the specification of one language into a flow chart compatible language. Using the Fortran, Cal, and charter options of the ADR package, a flow chart is produced which graphically illustrates the flow of logic through a program . The translators run on the Interdata 8/32's and produce output tapes which are processed on the IBM 370 facility for the Gould graphics plotter.

Automatic Interface Mnemonic Extractor System (AIMS). The AIMS system is an integrated set of programs developed to automatically extract, classify and identify the attributes of variables for programs written in Interdata Fortran, Assembler or a mixture of both languages. The AIMS programs execute on the Interdata 8/32's in three distinct phases. The first phase converts a specified release of the data base file (DED) into a structured data file for use by the second phase of AIMS. The second and third phases are the principal operational phases of AIMS. In the second phase. AIMS

processes any input source file by syntactically parsing the imbedded source code and extracting every variable mnemonic name. These variables are subsequently classified and identified to the system as global/local and input/output mnemonics. The system is capable of maintaining this classification through multiple levels of equivalences. The third phase of operation is essentially a report writer which formats and generates the requested detailed output reports. The AIMS processors can be invoked by any SDF user either in batch or on-line as a powerful interactive debugging aid. A number of options and capabilities are available to the user. For example, an on-line user may invoke the AIMS processor with the option to provide a scaled down data dictionary which is then automatically inserted into the source code of the user's program. Similarly, as part of the software change process, the configuration management group has the option to produce from one or more source programs an AIMS output tape which is directly input to the TACT/ITS system.

In summary, although only a few of the many tools available have been discussed, it can be seen that the commitment to automation and identification has resulted in the incremental development of tools, each providing a stepping stone in the sequential development process, and with each succeeding step more cost effective than the last. In particular, no tools have been as cost effective as those which have been developed for configuration management.

Software Change Order (SCO). The SCO is the vehicle by which proposed software modifications are documented, submitted to the Change Review Board (CRB) for approval and authorization, and tracked through development, test and installation. A simplified overview of the software change procedure is shown in Figure 9.

Header/Trailer. To maintain effective control of all system software components, all software related files have been augmented in format to include a header and trailer for identification. Utility programs have been designed to provide machine readable descriptive comment blocks for installation into the source modules. These source HEADERS are installed and updated interactively by the user. Header data includes such items as hierarchical code (HID), description, external file name, revision level, entry point and entry point descriptions, and a complete change history providing the date and description of all changes. Source Headers are initially installed directly into source programs using simple interactive "HDR" utility programs, and are similarly updated for revision levels and change history via "UPDHDR" programs. Every effort has been made to provide tools for the user which are simple and foolproof to use. As an example, the system responds to the command "HDR, file name extent" by clearing the CRT screen and displaying a blank "fill in the blanks" Header for the user. Information for the various fields is solicited on an entry by entry basis from the user. For each field, an appropriate prompt message including field name, length, and any special characteristics, is displayed to the user. Appropriate error messages are issued in response to missing mandatory information.

An additional feature provided with the Header Utility programs is the automatic generation of a TRAILER BLOCK at the end of the source code module. This module provides source line count, comment count, and other source quality factors. Most importantly, the format and the explicit data entries in the Header/Trailer Identification Blocks are produced by software in a uniform fashion so as to be machine readable by all other software tools.

Task/Overlay Generation. The SDF contains a number of programs which provide the bridge between change control authorization and the generation of an executable load module. Emphasis was placed on minimizing manual procedures and intervention in both the software change generation process (overlays) and in the configuration of an entire computer task (computer load). Checks were built into the utility programs to make automatic verification of compliance to the proper configuration prior to any processing of a change component. The complete set of configuration control programs are integrally linked to each other, beginning with the SCO processing, through the software change generation process, the acceptance tests process and finally, the revision and release of the approved software configuration.

CFIGUP represents a set of programs which administratively update and control the approved system configuration levels. All inputs are keyed to the processing of authorized software change orders. At any instance in time the CFIGUP data bases represent the approved state of the system for each and every component for a given release level. The CFIGUP lists are utilized by the other configuration control programs to not only ascertain compliance for processing but to create the entire task configuration for each computer as well. For example, the OLBATCH programs check source module format compliance, revision levels, set up job control runs and initiate batch job submittals for all controlled

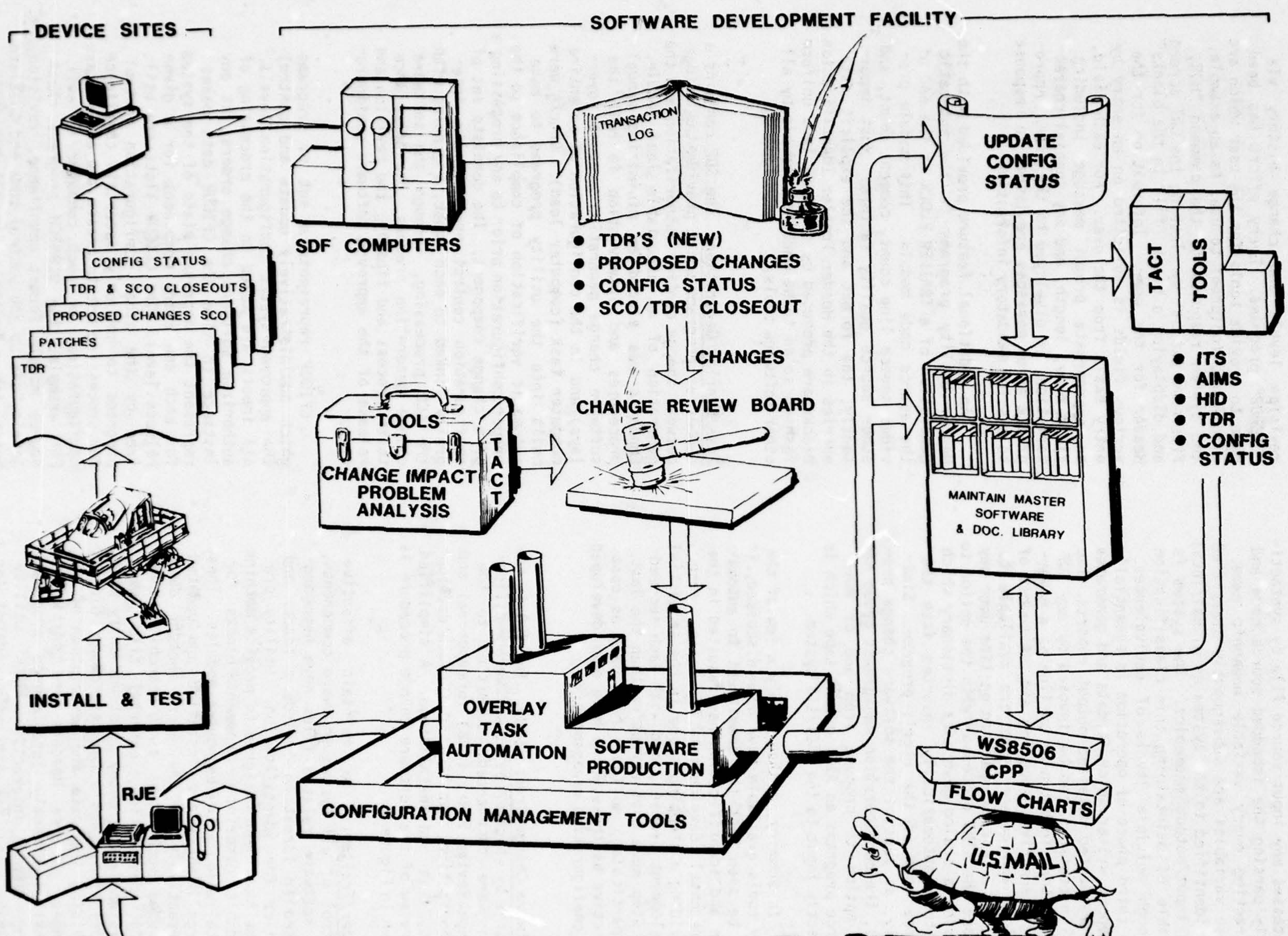

FIGURE 9 SIMPLIFIED SOFTWARE CHANGE FLOW

software compiles and assemblies. The OLCHECK programs perform automatic verification of compiler and assembly jobs.

The OLTET procedure represents a series of programs which link the software modules as determined from the configuration lists into machine executable core image formats (overlays/tasks).

In summary, the entire software change process from the generation of an SCO to the automatic synthesis of executable code requires little or no manual intervention.

THE FUTURE

Incremental change and growth are a way of life for large software systems, brought about by design evaluation, correction of deficiencies, aircraft updates and changes, the addition of features to enhance training value, instructor aids, fidelity enhancement, system improvements, and planned post-development efforts. To track and control all aspects of software with intimate visibility, to provide a change impact analysis rapidly and precisely, to maintain high levels of worker productivity and reliability in change, necessitates the automated software development environment of the SDF. For Grumman, the SDF has been a successful test bed for procedures and techniques of software engineering. The SDF can be likened to a prototype of the software factory concept and will continue to support software engineering research in such areas as design languages and automated test methodologies, while supporting other on-going trainer programs.

For the Navy, through an NTEC procurement, the capabilities of the SDF have been transformed into the new Software Support Facility (SSF) at NTEC, Orlando, Florida. The SSF provides a highly automated and integrated environment for the centralized software support function and is a major element in servicing and supporting training devices in multiple remote sites. The SSF provides NTEC the ability to reduce the cost of software support and increase life-cycle visibility, traceability and manageability of the software support process. The SSF now under construction at Orlando will be fully operational by the end of this year and may well be the subject of future technical papers from NTEC.

SUMMARY

In summary, the SDF provides the overall integrated environment for the management, control and visibility for software support; the direct accessibility to source programs, processors, tools and documentation; and direct data communication to the device sites. Most importantly, with the transference of SDF technology to the SSF facility for the Navy, there are no discontinuities in the transition from development to maintenance, leaving the support environment constant as responsibility for support changes hands. In effect, the support activity is afforded the benefits of visibility, control, and cost effectiveness presently available in the development environment.

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TRAINING REQUIREMENTS DETERMINATION DURING EARLY PHASES OF WEAPON SYSTEM ACQUISITION

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INTRODUCTION

The Weapon System Acquisition Process (WSAP) has generally been characterized by an inadequate consideration of the manpower, personnel, and training implications resulting from early design decisions. In response to this situation, the U.S. Navy has been involved in the design, development, and consistent improvement of a Military Manpower Versus Hardware Procurement (HARDMAN) methodology. The purpose of this methodology is to assess the implications of manpower, personnel, and training requirements early and continually throughout the WSAP.

As indicated in the reports describing the application of the methodology to the Shipboard Intermediate Range Combat System (Dynamics Research Corporation, 1978), the LSD-41 main propulsion plant (Dynamics Research Corporation, 1979a), and the Undergraduate Jet Flight Training System (Dynamics Research Corporation, 1979b), the methodology has been considered successful in generating manpower and personnel requirements for a proposed weapon system. However, due to a lack of contractual emphasis, the methodology has provided only a preliminary process for generating training requirements.

To satisfactorily close the loop of the HARDMAN methodology necessitates a Training Requirements Analysis (TRA) methodology step which will accurately determine the training implications associated with a proposed weapon system. This paper will propose a TRA step which provides the above determination and which is amenable to application early in the WSAP. The TRA has been designed in a manner which makes it compatible with the existing process of the HARDMAN methodology (see Figure 1) as described in Chapter 2 of Development of A Prototype HARDMAN Application - LSD-41 Propulsion System: Final Draft (Dynamics Research Corporation, 1979b).

OVERVIEW OF TRAINING REQUIREMENTS ANALYSIS

In order to determine training implications, the TRA step will provide the specification of an estimated training system design for a proposed weapon system. The design will include the following components:

- *the objectives of instruction
- *the sequencing of instruction
- *the methods of instruction
- *the media of instruction
- *the methods of assessment
- *the methods of remediation, and
- *the overall training system management

This design will not be the same as that which results from Instructional System Development (ISD). While some portion of the TRA procedures and techniques are similar to those in ISD, TRA will not result in the detailed products normally generated by ISD (e.g., the actual design of instructional materials, the actual construction of assessment items).

Following its specification, the estimated training system design will then be

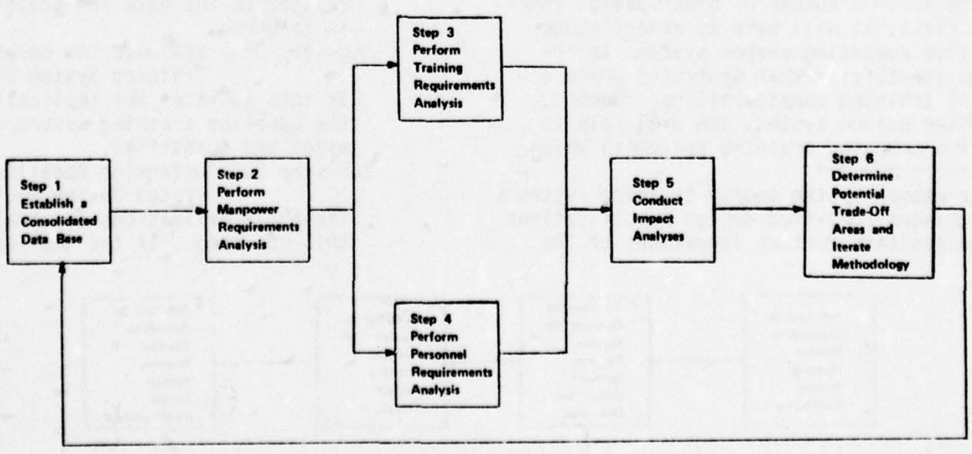

FIGURE 1 - THE HARDMAN METHODOLOGY

evaluated in order to determine and quantify its associated implications. The evaluation will tentatively be conducted in respect to the following implication categories:

*training system design consequences
- operational manpower requirements
- maintenance manpower requirements
- system ownership cost
- system design cost
- student time to complete
- real-time/simulator training time
- faculty training requirements
- support personnel training requirements
- student outcome predictability
- effects on career

*training system design cost/benefit

*training system design probability for success

*training system design adequacy

Each of these categories has been selected, and is capable of quantification, within the obvious constraint of not physically posessing the instructional products associated with the training system design under evaluation.

In any given application of the TRA, it is likely that a user (e.g., the Navy) may specify certain parameters which the quantified implications of the training system design may not exceed. Any quantified implications which do exceed the parameters will necessitate one or more modifications to the training system design and/or to the proposed weapon system design. In such a situation, evaluation and modification of both the training system and/or the proposed weapon system design would be conducted iteratively until the quantified implications of the training system design no longer exceed the specified parameters. Once the quantified implications fit all given parameters, the TRA process would be considered complete.*

In addition to determining the implications of a training system design, the TRA will also serve a number of other useful functions. First, it will help to select among alternative competing weapon systems in respect to identifying that system(s) which optimize(s) training considerations. Second, for a given weapon system, TRA will help to identify a proposed training system(s) which optimize(s) one or more user considerations. Third, TRA will provide substantial inputs to the ISD process during later phases of the WSAP.

*Further weapon system and/or training system design changes /detailed design specifications would necessitate further iterations of TRA.

TRAINING REQUIREMENTS ANALYSIS: THE METHODOLOGY STEP

The performance of TRA during the WSAP will result in extimates. In the early phases of the WSAP, the quality of the estimates will be a product of the existing knowledge concerning the proposed weapon system. However, as the WSAP progresses, the quality of the estimates will consistently improve.

Due to the inherent potential for error embedded in estimates, the TRA must constantly remain subject to revision as the quality of the data improves. In order to facilitate and encourage revision, the proposed TRA step has been designed to reflect a system's approach. That is, TRA may be described as 'the HARDMAN methodology in miniature' as internally it contains the elements of impact analysis, trade-off analysis and iteration.

The four sub-steps involved in TRA are depicted in Figure 2 and briefly defined below:

Sub-step 3a - Establish A Baseline Training System Curriculum

(In the HARDMAN methodology, a proposed weapon system is termed the baseline system. Similarly, the training system related to the proposed weapon system will be termed the baseline training system.) In this sub-step, the skills, knowledges and related objectives to be associated with the baseline weapon system are stated.

Sub-step 3b - Generate the Baseline Training System Design and Data Base

Based upon the previously stated objectives, a baseline training system design is specified. In addition, data related to the baseline training design is gathered.

Sub-step 3c - Evaluate the Baseline Training System Design

In this sub-step the implications of the baseline training system are determined and quantified.

Sub-step 3d - Determine Baseline Training System Design Modifications

The above evaluations are analyzed in this sub-step. If the implications

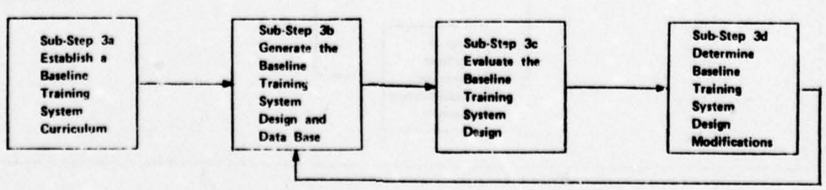

FIGURE 2- HARDMAN METHODOLOGY STEP 3: PERFORM TRAINING REQUIREMENTS ANALYSIS

of the baseline training system design exceed any user provided parameters, then changes in the baseline training system design are made and the changes iterated through the TRA. If the user provided parameters are not exceeded, then the TRA process is considered complete.

Each sub-step and its related activities are described as follows (see Figure 3 for the balance of this paper).

Sub-step 3a - Establish A Baseline Training System Curriculum

This sub-step involves a series of activities which will provide a foundation and focus for the succeeding sub-steps. The activities culminate in the statement of an estimated curriculum related to the job-skill areas demanded by the baseline weapon system under consideration. For purposes of this paper, a curriculum is defined as:

> the statement and sequencing of all the objectives to be mastered during a period of formal training related to a specific job-skill area.

As indicated previously, the job-skill area may be that of maintenance, operation, supervision, or some combination thereof.

The effort involved in curriculum development will vary depending upon the baseline weapon system. For those weapon systems which are similar (e.g., up-to-date replacements) for existing weapon systems, the establishment of an estimated curriculum may require little more than up-dating job-skills. However, for an entirely new weapon system, the generation of a complete listing of new job-skills and related curriculum efforts may be required. Of course, most baseline weapon systems will likely require an effort somewhere between these two extremes (e.g., the situation in which a baseline weapon system requires only the modification of a portion of an existing training system). A description of the three activites involved in the curriculum development sub-step is as follows.

Activity 3a.1 - Specify On-Job Skills

The primary input to this activity is the baseline task networks developed during the manpower requirements determination step of the HARDMAN methodology. These networks reflect a sequential listing of major job events as they occur in any maintenance/operational scenario. Thus the networks provide an initial conception of the maintenance, operation and supervision job-skills which will be associated with the baseline weapon system and which will require training.

Using the input from the baseline task networks, two general alternative methods for specifying actual on-job skills are available. The first is to conduct a hypothetical task analysis. This alternative would be followed in those situations where the baseline weapon system is an entirely new system or contains a significant number of new job-skill components. The procedures for conducting a hypothetical task analysis are described in Learning for Performance: Systematic Course Design Applied to Career Oriented Education (Vaughan, 1977).

The second general alternative for specifying on-job skills would be via the validation of an existing task analysis. This alternative would be employed in situations where the baseline weapon system is replacing an existing system and in which the job skills of both systems are relatively similar. In employing this alternative, the following general procedure would be followed:

1. the existing task analysis would be validated in respect to existing fleet operational requirements,
2. new job skills would be added to the task analysis to reflect new fleet operational requirements or new hardware/software additions,
3. existing job skills would be revised to reflect revised fleet operational requirements,
4. job skills within the existing task analysis which are no longer required by existing fleet operational requirements would be removed,
5. the existing task analysis would be reformatted (or restated) in a manner useful for further curriculum development activities.

Activity 3a. 2 - Convert Job Skills to Performance Objectives

In this activity each of the job skills would be converted into performance objective format. This conversion would result in a statement of required behavior, the mastery learning criteria associated with that behavior, and the conditions under which the behavior would be assessed. The performance objectives become the specific, measurable estimated learning outcomes of the baseline training system.

Activity 3a. 3 - Conduct Learning Analyses

Each performance objective would be subject to a learning analysis. Essentially, a learning analysis involves the statement and sequencing of enabling objectives (pre-requisite learning) required in order to achieve a specific performance objective (Gagne, 1975). The statement and sequencing of enabling objectives is accomplished employing an established hierarchy of learning (e.g., Bloom's Taxonomy of Educational Objectives, Gagne's Varieties of Learning, Ellis, et.al. Instructional Quality Inventory).

The major outcome of the curriculum establishment sub-step would be a baseline training system curriculum. In addition to providing a job skills and related objectives

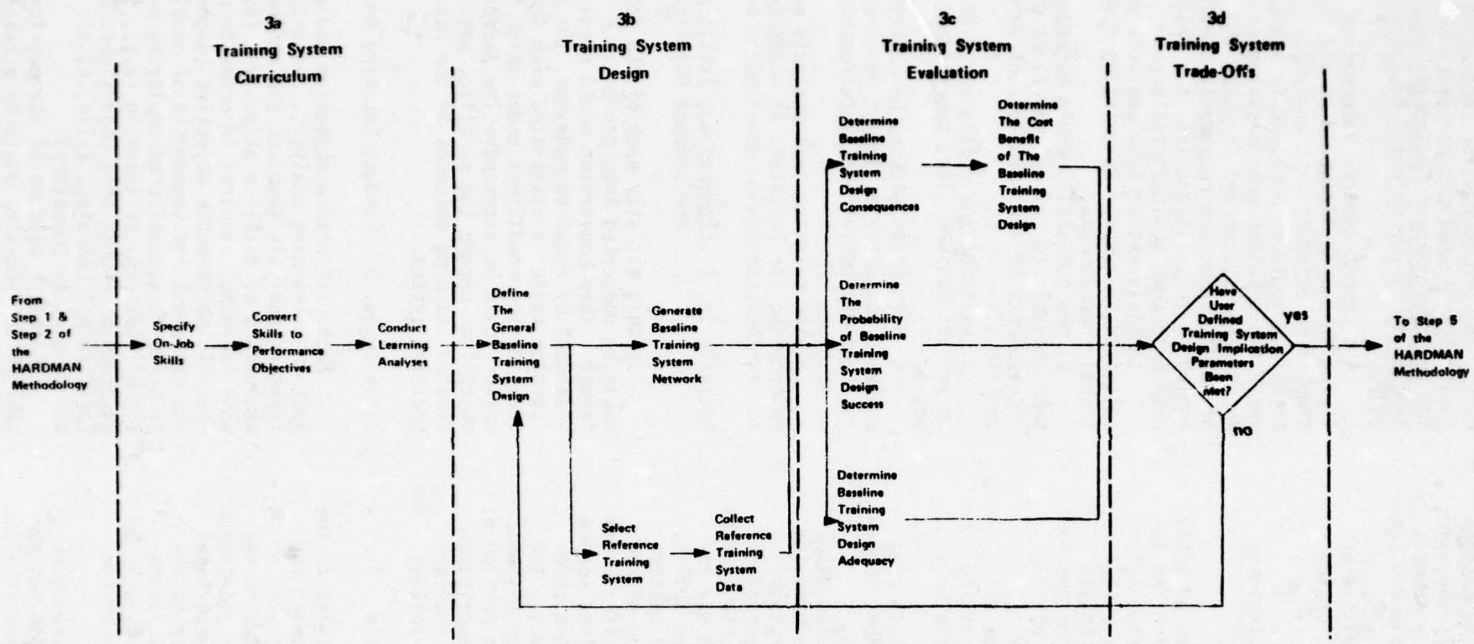

FIGURE 3– PERFORM TRAINING REQUIREMENTS ANALYSIS (EXPANDED VERSION)

foundation upon which a baseline training system design may be generated, the sub-step would also:

*assure that present and future job skill requirements are incorporated into the baseline system design,

*focus future learner and instructional designer attention via the statement of performance and enabling objectives,

*assure that the content of the baseline curriculum is appropriately sequenced via the learning analyses, and

*assure that alternative baseline training system designs (as required) are developed from the same basis and are thus amenable to comparisons.

Sub-step 3b - Generate the Baseline Training System Design and Related Data Base

The baseline training system design describes a training system which will satisfy those maintenance/operation/supervision skill needs specified in Activity 3a (note: a given baseline weapon system could require a number of different baseline training systems; each designed to satisfy a specific job area). In this sub-step both general and detailed designs of the baseline training system are generated. Further, a data base related to the baseline training system is also generated. This data base is used in later steps for evaluating the baseline training system design.

Activity 3b. 1 - Define the General Baseline Training System Design

There are two parts to this activity. In the first part the baseline training system is generally defined. This general definition reflects judgmental decisions made in terms of the following training system components:

*Training Sequencing Component - this refers to the sequencing of units of instruction (a unit is defined as a single performance objective and its related enabling objectives), e.g., may be characterized as sequencing by perceived complexity, sequencing by perceived transfer of learning value, sequencing by equipment system.

*Training Method Component - this refers to the general format to be used for training, e.g., may be characterized by individualized instruction, self-paced instruction, computer managed instruction, instructor led instruction.

*Training Media Component - this refers to the general kinds of media to be employed, e.g., may be characterized by motion pictures, simulator, textbook, programmed instruction, computer assisted instruction.

*Training Assessment Component - this refers to the general ways in which students will be tested during training; e.g., may be characterized by paper and pencil, on-job performance, simulated performance, oral interview.

*Remedial Assistance Component - this refers to the general ways in which student learning problems will be corrected; e.g., may be characterized by peer tutoring, motivational intervention, automatic feedback.

*Training System Management Component - this refers to the way in which overall management of the training will be conducted; e.g., may be characterized by computer managed instruction, personalized management system, instructor management.

For example, a hypothetical baseline training system may be generally defined as follows:

*Training Sequencing Component - instruction will be sequenced according to the equipment system being learned and for the piece of equipment according to complexity.

*Training Method Component - the methods of instruction will be primarily instructor led for complex skills and self-instruction for non-complex skills.

*Training Media Component - instructor led segments of instruction will use a lecture/textbook media while self-instructional segments will employ linear programmed instruction.

*Training Assessment Component - all assessment will be conducted via on-job performance, non-job related assessments will not be conducted.

*Remedial Assistance Components - the instructor will recognize learning problems and verbally provide remediation.

*Training System Management Component - all management tasks will be completed by the instructor.

Any single training system component characteristic or combination of characteristics may be selected in developing the general definition of the baseline training system. These characteristics may emanate from an array of sources.*

In any discussion of training, training

*e.g., the content of the baseline curriculum, the Mission Element Needs Statement, perceived learning problems, research on teaching/learning, experimental considerations, a desire to simply update an existing training system, the requirement to modify only a portion of the existing training system, potential student capabilities as measured by standardized test scores.

component characteristics are presented as though there is a general understanding of their meaning. However, such is not the case. For example, to some individuals the characteristic 'written self-instruction' implies pages containing 350 (more or less) typed words. Yet, to other individuals it may imply pages containing enough words to present a stimuli for learning, provide a model of expected student performance, provide prompts for learning, and guide student thinking. Obviously, in the case of 'written self-instruction,' the difference between these perceptions has a significant effect on (for examples):

*the skills required of the person developing the written self-instruction
*the time involved to develop the written self-instruction
*the time required for a student to master the contents of the written self-instruction

Thus, the second part of this activity requires that the training component characteristics within the general baseline training system description be thoroughly defined. Essentially, each component characteristic which may become a part of the baseline training system design requires careful definition. Without this definition, the evaluation of a single (or competing) baseline training system design(s) will be inadequate.

Activity 3b.2 - Select the Reference Training System

The function of the reference training system is to serve as a data source from which baseline training system design data may be generated through extrapolation. Thus, the reference training system selected should contain features which make it directly comparable to the general baseline training system design (e.g., similar type of curriculum, similar training component characteristics). For example, if the baseline curriculum contains sophisticated technological job skills and the general baseline training system design incorporates the component characteristics of self-paced, computer assisted instruction, then a similar reference training system should be selected. In certain cases the reference system may be the existing training system which is being replaced. However, assuming that the general baseline training system design incorporates unique component characteristics or is designed for an entirely new weapon system, the reference training system may be composed of:

*a similar existing training system
*portions of similar existing training systems
*related training system data gleaned from the literature on training.

Activity 3b.3 - Collect Reference Training System Data

Data to be acquired on the reference training system is specific. Data should be collected on each training component characteristic which is to be a part of the baseline training system design. The accuracy of the data collected will be a function of how closely the component characteristics of the reference training system match the component characteristic definitions generated in activity 3b. 1. Thus, the data collected may require modification based upon any differences in characteristic definition.

The data collected for each component characteristic should include:

*time to design/develop
*cost
*expected student performance
*faculty training requirements
*support personnel training requirements
*career impacts
*expected design problems

Each data item should be sufficiently detailed to permit accurate extrapolation to the baseline training system (e.g., the cost factors obtained for the design and development of a single page of 'written self-instruction' in the reference training system should be of sufficient detail to permit the generation of similar costs for the baseline training system).

Activity 3b. 4 - Generate the Baseline Training System Network

A training system network is a pictorial display of the terminal and enabling objectives within a given training system (see Figure 4). The network indicates the sequence in which the performance objectives and enabling objectives will be learned (which will reflect the learning analysis except in those cases where the sequencing of objectives is arbitrary). Further, the network indicates, for each objective, the specific methods and media to be used, the specific methods of assessment and remediation to be used, and the specific training management technique to be used. Each of these decisions is made based upon the general definition of the baseline training system design (Activity 3b. 1) massaged by convenience, research findings, expected benefits, task difficulties, requirements for practice, and kind of learning involved.

Essentially, the construction of the baseline training system network provides the specific design for the baseline training system. In the HARDMAN methodology, it is this specific design which is used (along with manpower and personnel determinations) in the conduct of impact analyses and tradeoff studies related to the baseline weapon system. However, due to the relatively soft nature of training, the baseline training

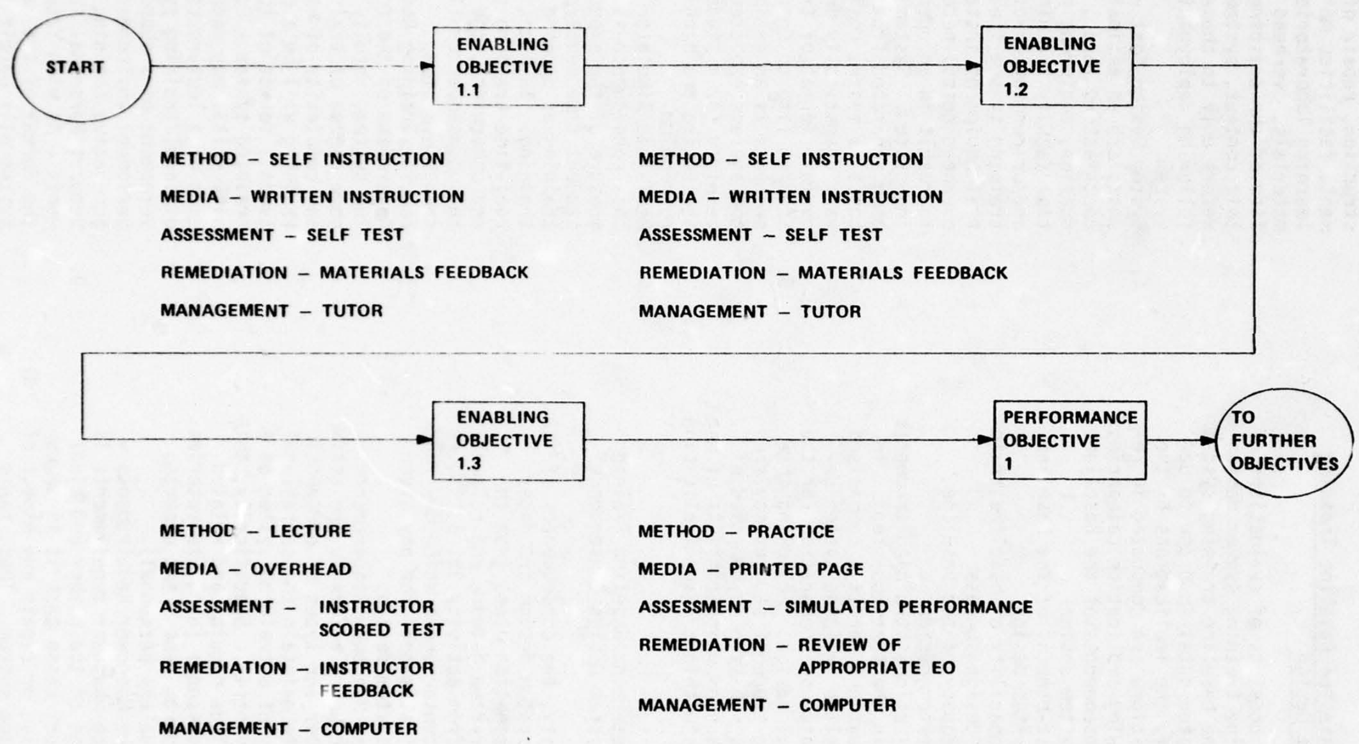

FIGURE 4– PORTION OF A BASELINE TRAINING SYSTEM LEARNING NETWORK

system design is iteratively subjected to evaluation and tradeoffs within the TRA. The need for evaluation and tradeoffs within the TRA provides the rationale for the next two sub-steps.

Sub-step 3c. Evaluate the Baseline Training System Design

This sub-step consists of evaluations of the specific baseline training system design (as presented in the baseline training system network and associated data) in order to determine and quantify the implications of the design. The evaluations are conducted in respect to the following implication categories:

*estimated consequences of the baseline training system design
*estimated cost-benefit of the baseline training system design
*estimated probability of baseline training system design success
*estimated adequacy of the baseline training system design

Based upon the evaluations, training tradeoffs may be conducted (in the next sub-step). In addition, the evaluations permit a comparison of alternative baseline training system designs (as appropriate) in preparation for the selection of a final design. Following that selection, training tradeoff studies may then be conducted. This sub-step is composed of four activities, each of which consists of one or more evaluations within a given implication category:

Activity 3c. 1 - Determine Baseline Training System Design Consequences

In this activity, the consequences of the baseline training system design are determined. This determination stems from the baseline training system network and related quantifiable data from activity 3b. 3. There are presently ten consequences which may readily be quantified (estimated) for any given baseline training system design:

1. Operational Manpower Requirements - This consequence refers to the estimated number and types of personnel required to maintain the operational capability of a training system on a day to day basis. Specifically, this would include faculty and related support personnel (e.g., secretaries, media support, assessment experts, facility upkeep personnel).
2. Maintenance Manpower Requirements - Maintenance manpower requirements is an estimate of the number and kinds of personnel whose task it is to update, revise or repair any aspect of the training system. Thus, these personnel would run the gamut from instructional technologists to media equipment repair personnel to technical writers.
3. System Ownership Cost - System ownership cost is an estimate of a training system's operational costs (e.g., materials, faculty and student maintenance, revision of instruction, repair of media equipment, facilities maintenance of learning laboratories, supplies and materials, overhead costs) for the life of the training system. In this context, system ownership costs refers only to those costs accruing following deployment of the training system.
4. System Design Cost - System design costs are an estimate of all those cost factors (e.g., materials production, equipment purchases, initial faculty training, construction and/or renovation of facilities, training system field testing, initial equipment installation, design overhead costs) necessary in order to result in an operational training system. System design cost has been separated from system ownership costs as system design costs may vary dramatically dependent on the overall format of training.
5. Student Time to Complete - This consequence is an estimated measure of the average expected amount of time required for a student to master the entire training system curriculum.
6. Real-Time/Simulator Training Time - This consequence is an estimated measure of the expected amount of student time devoted to simulator training as opposed to real-time training. In light of the costs of real-time training (both financial and otherwise), the importance of this consequence will likely increase overtime.
7. Faculty Training Requirements - Regardless of the format of a training system, faculty will require some degree of training. The time and complexity of estimated faculty training will be a product of the overall format of the baseline training system. For example, faculty skills may range from the conduct of a lecture (for a more traditional training system to the development of a supportive interpersonnel environment for a more innovative training system).
8. Support Personnel Training Requirements - As with faculty training, the format of the baseline training system will permit an estimate of the kinds and complexity of support training required. For examples, the use of new hardware may require the training of technicians, while

certain kinds of media may require the training of educational technologists.

9. Student Outcome Predictability - This consequence does not refer to what is learned, but rather to the estimated consistency of learning. Some training system formats may allow (even encourage) a diversity of achievement while others may result in highly consistent achievements.

10. Effects on Career - This consequence is an estimate of the effect of the training system on a student's future career. The inclusion of this consequence stems from studies related to the Navy's Integrated Personnel System (IPS). The IPS studies indicated that dramatic changes in training can have significant effects (both negative and positive) on careers.

As indicated previously, data related to each of the consequences is developed from the training data base (Activity 3b. 3). However, certain of the training program consequences may require data which is not readily available. For example, the training data base may not have sufficient data on faculty training vis-a-vis the more complex faculty skills which may be required by a given baseline training system design. Thus, reference training system data may require reinforcement with data from other existing training systems or from related literature (Note: any further data collected would be added to the training data base).

The following comments on training design consequences should be noted:

*Each of the training system design consequences is an estimate based on existing data, thus, the consequences are subject to revision as the quality of data improves.

*The ten training system design consequences are not intended to become a finite list. Other consequences may be selected for measurement depending upon the baseline weapon system under consideration.

*The quantification of certain design consequences helps in stimulating data of value in quantifying other consequences. For example, the complexity of faculty training requirements will lead to questions of assignment flexibility (due to faculty illness, leave, etc.). the results of the assignment flexibility analysis will help to further quantify the student time to learn consequence and thus the system ownership cost consequence.

Activity 3c. 2 - Determine the Cost-Benefit of the Baseline Training System Design

All training system designs are intended to produce desirable outcomes. However, in order to judge desirability, decision makers are concerned with the benefits and costs of a given design. Cost-benefit analysis includes estimates of both cost-analysis and benefit-analysis. Each of these terms is defined as follows (Human Resources Research Organization, 1973):

*cost analysis - a process for determining or estimating the dollar cost of training (both system ownership costs and system design costs) per student or groups of students.

*benefit-analysis - a process for determining or estimating the dollar value of specific benefits gained from training. Essentially, benefits analysis requires the identification of those benefits or portions thereof that can be directly attributed to training.

*cost-benefit analysis - a process for determining or estimating the dollar cost of those benefits directly attributable to a training system design. Further, cost-benefit analysis permits the comparison of alternative training system designs or of variations of the same design.

Activity 3c. 3 - Determine the Probability of Baseline Training System Design Success

Failing an analysis of success, any baseline training system design has the same general probability of success as any other design. As baseline training system designs cannot be empirically tested prior to their actual development and implementation, a method for accurately estimating the probability of their success is desirable. In order to satisfy this probability of success requirement, the TRA will employ a variation of a technique know as 'fault tree analysis' (Wood et al, 1979).

The fault tree analysis technique provides an indication of the most likely points of failure which could occur within any given baseline training system. The technique requires a concise and logical step by step description of the various combinations of potential or possible occurences within a baseline training system design which could result in failure of the system. Further the technique will graphically portray and systematically depict the probable failure event sequences which can lead to failure of a key learning outcome.

When a fault tree analysis is completed, mathematical formulas are applied to

determine the strategic paths leading to undesired events. Thus, through a summation process, a probability of success of a given baseline training system design may be determined. The overall value of the fault tree analysis technique is that it will provide both a clear indication as to the weakest link within a given baseline training system design as well as indicating the comparative success probabilities for alternative designs.

Activity 3c. 4 - Determine the Adequacy of the Baseline Training System Design

The adequacy of a baseline training system design may be defined as "the ability of the training system network components to move a student from an entering capability level to a terminal capability level." For purposes of this evaluation, the estimated adequacy of the training network will be measured as follows (Mulligan & Funaro, 1979):

*Training System Ability to Satisfy Recall Learning Requirements - Recall learning requirements are defined as the amount and complexity of recall required by a terminal performance objective. Adequacy will thus be a function of the training system network's ability to satisfy these recall requirements. The adequacy of the baseline training system network will normally be measured via the estimated amount of student rehearsals necessary in order to meet the recall requirements.

*Training System Ability to Satisfy Skill Performance REquirements - Skill performance requirements are defined as the complexity of performance required by a terminal performance objective. Adequacy will thus be a function of the training system network's ability to satisfy these requirements. The adequacy of the training network will normally be measured by its estimated ability to satisfy specific psychomotor, conceptual learning, and perceptual discrimination requirements.

Sub-Step 3d - Determine Baseline Training System Design Modifications

This final sub-step employs the results of sub-step 3c in generating an answer to the following:

HAVE USER DEFINED TRAINING SYSTEM DESIGN IMPLICATIONS PARAMETERS BEEN MET?

By user defined it is meant that the user may provide parameters for one or more of the implication categories within sub-step 3c. The comparison of these parameters against each of the implication categories will permit the identification of any undesireable outcomes of the baseline training system design; i.e., quantified baseline training system design implications which exceed user parameters.

If there are no undesireable outcomes, then the results of the TRA (quantified implications of the baseline training system design) will proceed to Step 5 of the HARDMAN methodology where the impacts of manpower, personnel and training implications, both individually and collectively, will be identified. If, on the other hand, there are undesireable outcomes, then changes will be made to the baseline training system design (activity 3b. 1) or the baseline training system network (activity 3b. 4). These changes will be iterated through sub-step 4c in order to generate modified baseline training system design implications. This iteration process will continue until an acceptable array of quantified training system design implications (via user stated parameters) are obtained.

CONCLUSION

The TRA described in this paper enhances the overall applicability of the HARDMAN methodology. It does this by estimating/quantifying the training implications associated with a proposed weapon system design both early and continually in the WSAP. Unfavorable implications may then be alleviated. This may be accomplished either through the modification/replacement of the baseline training system of through a modification in the design of the baseline weapon system.

The TRA is characterized by, and owes its potential accuracy to, the following:

1. The tendency towards objectivity in all TRA sub-steps and related activities.
2. The specification of the baseline training system design as a result of a detailed baseline weapon system curriculum matched to job skills.
3. The specification of the baseline training system design in sufficient detail to allow quantification.
4. The evaluation of the baseline training system design via the estimates of training system consequences, training system cost-benefit, training system probability for success, and training system adequacy.
5. The provision for TRA internal trade-off and iteration based upon evaluations of the baseline training system design.
6. The provision for revision of the baseline training system design (and related evaluations) as more accurate data becomes available.

In addition to the identification of the training implications associated with a baseline weapon system design, the TRA will also serve a number of other useful functions.

Among these are to select among alternative competing weapon system designs, to help identify optimum training systems, and to provide substantial inputs to the ISD process during later phases of the WSAP. In the future, the TRA can easily be adapted for computer operation.

REFERENCES

1. Dynamics Research Corporation. Development of a Prototype HARDMAN Application - Final Report - Volume 1. Report No. R-267U, Dynamics Research Corporation, Wilmington, Mass., 1978.

2. Dynamics Research Corporation. Development of a Prototype HARDMAN Application; LSD-41 Propulsion System - Final Draft. Report No. E-4932U-1, Dynamics Research Corporation, Wilmington, Mass., 1979a, pps. 2-1 - 2-18.

3. Dynamics Research Corporation. Application of The HARDMAN Methodology to VTXTS Flight Vehicle Maintenance Manpower Requirements. Report No. E-5088U , Dynamics Research Corporation, Wilmington, Mass., 1979b.

4. Gagne, R.M. The Conditions of Learning; Holt, Rinehart and Winston, Inc., New York, 1970, pps. 237-276.

5. Mulligan, G.E., and Funaro, J. Issues in the ISD Process: the NAVAIR/NAVTRAEQUIPCEN Model. Report No. IH-309, Naval Training Equipment Center, Orlando, Florida, 1979, pps. 23-29.

6. Spangenberg, R.W., Riback, Y., and Moon, H.L. The State of Knowledge Pertaining to Selection of Cost Effective Training Methods and Media. Report No. 73-13, Human Resources Research Organization, Alexandria, Virgina, 1973, pps. 38-47.

7. System Automation Corporation and Chief of Naval Operations Studies and Analysis Program. Military Manpower Versus Hardware Procurement (HARDMAN) Study Report. Report No. ________ Department of the Navy, Office of the Chief of Naval Operations, 1977, page 1-2.

8. Vaughan, Jr., J.J. Learning for Performance: Systematic Course Design Applied to Career Oriented Education. Unpublished Manuscript, 1977, pps. 75-78.

9. Wood, R.K., Stephens, K.G. and Barker, B.O. "Fault Tree Analysis: An Emerging Methodology for Instructional Science", Vol. 8, 1979, pps. 1-22.

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COMMON MODEL TEAM TRAINER

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INTRODUCTION

Submarine sonar and fire control training has entered a new era - one of increased system complexity and increased training requirements. Indeed, the onset of embedded computer-based systems,such as AN/BQQ-5,complicates the situation even further by allowing differently performing versions of similar-looking systems.

The purpose of this paper is to propose both a technical approach and a development plan for a new generation of submarine combat team trainer systems, emphasizing the use of common problem control, target model and environmental model modules. The Common Model Team Trainer (CMTT) will provide a consistent level of training realism and capability across multiple trainer devices and allow maximum utilization of Navy resources both at development laboratories and at trainer installations.

Consideration of this approach is especially significant now since most current trainers are scheduled for system rearchitecture or upgrade over the next five years - an excellent time frame for CMTT. This approach is applicable to sonar and fire control trainers currently installed and/or planned for SSN, SSBN and TRIDENT.

CMTT - TECHNICAL APPROACH

The Common Model Team Trainer is a departure from the current trainer design approach. A few words about the historical considerations leading to this proposal may be beneficial. This is followed by a conceptual definition of CMTT and some relevant hardware considerations of CMTT.

CMTT - HISTORICAL PERSPECTIVE

In the past, trainer development has been a more or less evolutionary process, keyed to the development of new capabilities in the sonar or fire control equipment suite. Simply described, these trainers consisted of:

- o a problem control function,
- o target and own-ship models,
- o ocean and environmental models, and
- o the tactical sonar/fire control system.

These trainers were relatively simple, "unit" trainers for individual operator training (Figure 1).

In recent years, greater emphasis has been placed on training the sonar or fire control operator as part of a team, leading to the development of the 21A Series Submarine Combat System Trainer (SCST). The SCST is comprised of attack center and sonar control room trainers capable of operating in one of several modes:

- o stand-alone sonar team - sonar party only,
- o stand-alone fire control team - fire control party only,
- o attack team - sonar and fire control operating together, and
- o joint task team - two or more attack teams operating in consort.

The SCST may be considered to be a second generation training device and is currently planned to support the following range of equipment suites:

- o Sonar
  - oo FBM - AN/BQR-7, BQR-21, BQR-15/23
  - oo TRIDENT - AN/BQQ-6
  - oo SSN - AN/BQQ-5
- o Fire Control
  - oo FBM - Mk 113 Mod 9
  - oo TRIDENT - Mk 118
  - oo SSN - Mk 113 Mod 6, 10, Mk 117

The development of the corresponding trainer devices has led to an effort characterized by different approaches to problem control and target and environmental modelling. For example, FBM Sonar Operator Trainer (FBM SOT) and AN/BQQ-5 Sonar Operator Trainer, Device 21B64 (21B64), each have different problem con-

trol capabilities for own-ship and target initiation. One allows 6 targets, another 10; one allows target initiate and delete during an exercise, another doesn't; one has dedicated problem control function switches, the other doesn't. SCST devices have still another set of capabilities.

This approach to trainer development has had the following effects:

1) multiple development efforts (and costs) for similar functions,

2) multiple maintenance efforts for models and data,

3) non-uniform capabilities in problem control and target and environmental modelling elements,

4) increased training time to qualify instructors, and

5) anticipated trainer to trainer integration difficulties due to different models.

In view of these considerations, the question arises now, can we afford the luxury of tailored trainer systems for current and future tactical sonar and fire control suites? It is likely that we cannot.

As proposed in following paragraphs, the solution could be to adopt an approach based upon common modules which will support users across a broad spectrum of sonar and fire control team training problems.

In defining CMTT performance requirements, we must first look at the systems addressed. Each of the systems mentioned in the previous paragraphs, as well as SSBN and SSN on-board trainers, are excellent potential candidates for CMTT. Referring to Figure 1, it can be readily seen that functions to the left of the *interface can be made common. Indeed, there* is little or no reason for differences in any of these functions. Instructor control capabilities, threat characteristics, and the submarine environment are not dependent upon the platform modelled as own-ship.

CMTT proposes separation of these common functions into common modules for problem control, target and own ship models and environmental models and developing (or utilizing) system unique modules for tactical system and interface functions (Figure 2).

CMTT - CONCEPTUAL DEFINITION

Simply put, CMTT will provide data at the rate and resolution necessary to support the requirements of applicable trainer devices. At the CMTT module level, this is an inclusive requirement; that is, each CMTT module will support the most stringent anticipated requirement of all user tactical systems. Systems which require less data, at lower rates, or lesser resolution will have the CMTT outputs adjusted in their interface module (Figure 2).

It is necessary to define these modules further and to realize that through proper partitioning of functions, each module can be made to support multiple trainer configurations; i.e., a common module for multiple installations.

Problem Control Module - accepts inputs from an instructor, a team trainer driver computer and from the tactical system. Typical functional characteristics of the problem control module would be:

- o problem control (run, freeze, etc.),
- o target and own-ship initialization and control,
- o environmental parameter control (sea state, fixed and directional noise sources),
- o simulated faults, and
- o trainee monitoring and evaluation.

Outputs will be provided to each of the other modules as necessary to support their functions. For example, position data will go from the Problem Control Module to the Environment Model so that propagation loss may be determined for each target.

Target and Own-Ship Model Module - accepts target initialization and deletion requests from problem control and generates the necessary acoustic characteristic data in accordance with its standard models. The own-ship model will be selectable across the applicable hull configurations. The target module outputs to the environmental model and to problem control for display to the instructor.

Environment Module - accepts target/own-ship relative position and dynamic data and generates propagation loss (multiple paths), angle of arrival, time of arrival, phase. In addition, the environment module will do noise processing for fixed and directional noise sources as well as reverberation processing. The

environment module provides signal data to the interface module which will convert the data to the trainer device configuration required.

Interface Module - while not a CMTT module, it is a key to CMTT usage since this module converts this digital "in-the-water" signal to a form usable by the trainer tactical system configuration selected. In general, the interface module can be characterized as:

- o Full digital - tactical sonar software (or part) stimulation, such as TSOT,
- o Digital/Analog Audio Generator - tactical hardware/software stimulation, such as FBM SOT, and
- o Sonar Model - tactical fire control system stimulation, such as 21A37.

Tactical System Module - accepts CMTT inputs via the interface module, and direct problem control inputs from the problem control module.

Note that the interface and tactical system modules will take standard CMTT *outputs and convert them for use in their* own system; CMTT is essentially independent of these tactical system configurations. As shown in Figure 2, the tactical system configuration could be tactical software or the full tactical equipment suite. (A possibility not shown is one which includes partial tactical hardware and/or software such as the current 21B64 configuration.)

In addition to providing the trainee interface, the tactical system *module* will, in turn, provide trainee action data back to problem control for monitoring and trainee evaluation purposes.

CMTT - HARDWARE CONSIDERATIONS

Detailed statements of hardware (or software) architecture cannot be made until the requirements analysis and initial design work is done. However, some preliminary observations may be made.

Each module may be readily implemented on a series of independent mini (or micro) computers processing asynchronously. Current modules performing similar functions require less than 32k bytes of memory and process in milliseconds. For example, the propagation model in the TRIDENT Sonar Operator Trainer (TSOT) uses 6500 instructions and the environment model in the Mk 117 development system (at NUSC/Newport) uses 3000.

(These are supported by non-resident propagation loss data tables which can be extensive in length.) A similar partitioning of functions into modules is currently being studied for TSOT as well as for SCST application.

An additional feature of this parti*tioning may be the ability to have high*-speed memory associated with each modules' processor. This will minimize time delays currently inherent in such activities as target initialization (for example, weapon firing *in 21B64) and propagation* loss calculation (using table look-up schemes). Rather than accessing a disk in competition with other modules, each module can access its required data at high speed with no contention problem.

CMTT - DEVELOPMENT PLAN

The current situation is that several trainers are being built in several different ways, incurring multiple costs and possibly impacting upcoming integration efforts. The CMTT development plan proceeds from these current activities and phases into a long-term team trainer development program. The plan consists of four phases:

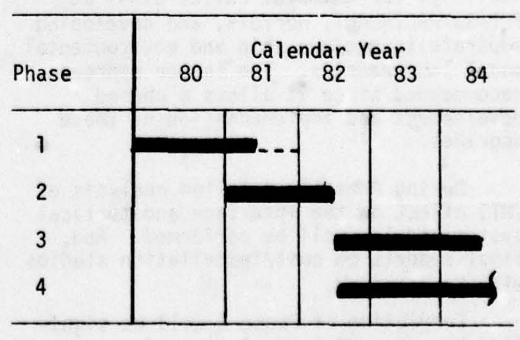
1) *Phase 1 - Analysis and* Standardization,

2) Phase 2 - Near-Term Implementation and Operational Demonstration,

3) Phase 3 - Long-Term Implementation, and

4) Phase 4 - Maintenance.

Figure 3 provides an overview of the CMTT development plan. A schedule for implementation could be as shown below:



Phase 1 - Analysis and Standardization

This phase of CMTT development is characterized by an assessment of training requirements via-a-vis the data re-

quirement for each of the applicable Sonar and FSC suites.

A high-level requirements document (an A-level specification in MIL-STD-490 parlance) and interface design specifications (IDS) (between modules) will be generated. The A-level spec and IDS's will specify CMTT performance at a level necessary to meet the most stringent requirements of each of the supported Sonar/FCS suites. Particular attention will be given to partitioning of tasks, and I/O parameter definition, data rates, resolution and protocols.

During Phase 1, problem control requirements will be standardized, supporting each of the training modes covered previously. Target model and environmental modelling requirements, particularly for Sonar training, will be clarified; and models and data will be standardized.

Interface and tactical system module effects will be analyzed. Preliminary recommendations for CMTT implementation in developed systems will be generated.

Finally, Phase 1 will include a cost/installation study.

Phase 2 - Near-Term Implementation

Near-term implementation consists of selecting CMTT hardware and implementing the A-level spec and IDS's applicable to problem control and target/own-ship and environment modules. Emphasis will be placed on continued interaction with Fleet users of CMTT during this entire phase. Phase 2 can be accomplished either entirely on a development system allowing full verification of the CMTT concept, or partially by installing problem control upgrades in all trainer devices at one facility, for example, Device 21A41 at FLEASWTRACENLANT, Norfolk, and developing separate target/own-ship and environmental model laboratories. The latter approach is recommended since it allows a phased development and implementation of these upgrades.

During Phase 2, detailed analysis of CMTT effect on the interface and tactical system modules will be performed. And, final reports on cost/installation studies will be prepared.

Completion of Phase 2 will be signified by successful completion of an operational demonstration of CMTT and validation of its capabilities by Fleet (user personnel). Decision to proceed to Phase 3 and 4 will be contingent upon satisfactory performance in the demonstration and a postive cost/benefit analysis for a long-term CMTT implementation and maintenance.

Phase 3 - Long-Term Implementation

Long-term implementation would consist of installing CMTT in each existing trainer device and designing CMTT into new trainer devices. This could be accomplished via an Engineering Change (ECP) which would:

- o modify the applicable interface modules to accept CMTT inputs,
- o install CMTT hardware and software, and
- o remove hardware and software no longer required.

This phase could be accomplished in approximately two years, using phased deliveries to existing trainer sites and to any new systems to be built in three to five years.

Phase 4 - Maintenance

One of the primary advantages of CMTT would be the consolidation of development and maintenance efforts, minimizing the possibility of redundant maintenance efforts and their associated costs. Maintenance of CMTT problem control, target/own-ship model and environment modules would be performed by Navy laboratories. Updates to each module would be made as new data or model approaches evolved.

An important feature of the maintenance phase would be assignment of a "Configuration Manager" for each of the CMTT modules. The CMTT Configuration Manager would be responsible for:

- o establishing procedures for CMTT improvements,
- o maintaining Fleet (user) interface for review and concurrence with upgrade plans,
- o maintaining problem control module,
- o maintaining target/own-ship and enviromenta models and data,
- o coordinating Fleet (user) inputs to model and data upgrades,
- o coordinating releases of updates to CMTT installations (with special attention to updated target data).

Note that one of the initial CMTT roles is to define a system with broad interface and performance capabilities. The CMTT Configuration Manager would complement this role by ensuring development of future upgrades with the following considerations:

- o minimum impact on module interfaces,
- o uniform distribution of target/own-ship and environmental data, and
- o maximum Fleet (user) feedback prior to release of an update.

Phase 4 would be an on-going phase which would support new developments as required for CMTT to support future tactical Sonar/FCS upgrades.

CONCLUSION

CMTT is a system whose benefit to the Fleet would increase with each new application. The commonality inherent in problem control, threat characteristics and environmental parameters required for Sonar/FCS training dictate a common model approach.

Each of the current SSBN, TRIDENT, and SSN Sonar/FCS team trainers are considering upgrades over the next one to five years which could support adoption of CMTT. Improvements in some of these trainers will be extensive, resulting in "new" developments which could adopt the CMTT approaches.

CMTT adoption at this time would:

- o minimize development costs for new or upgraded systems,
- o centralize development and maintenance activities,
- o maximize utilization of Navy instructors (able to operate multiple trainer devices),
- o provide uniform capabilties in all trainer-unique functions, and
- o ease integration in an attack or joint task team environment.

Essential to its success are:

- o strong Navy direction across program and organizational boundaries,
- o early system requirements analysis,
- o system architecture definition providing for significant growth and upward compatability,
- o strong commitment to long-term target/own-ship and environmental model and data maintenance.

Endorsement of the CMTT approach would provide a new opportunity for the Navy to assure uniformly high standards of training across all trainer devices.

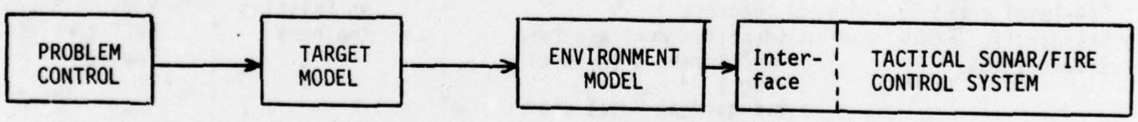


Figure 1 - TRAINER SYSTEMS - A HISTORICAL PERSPECTIVE

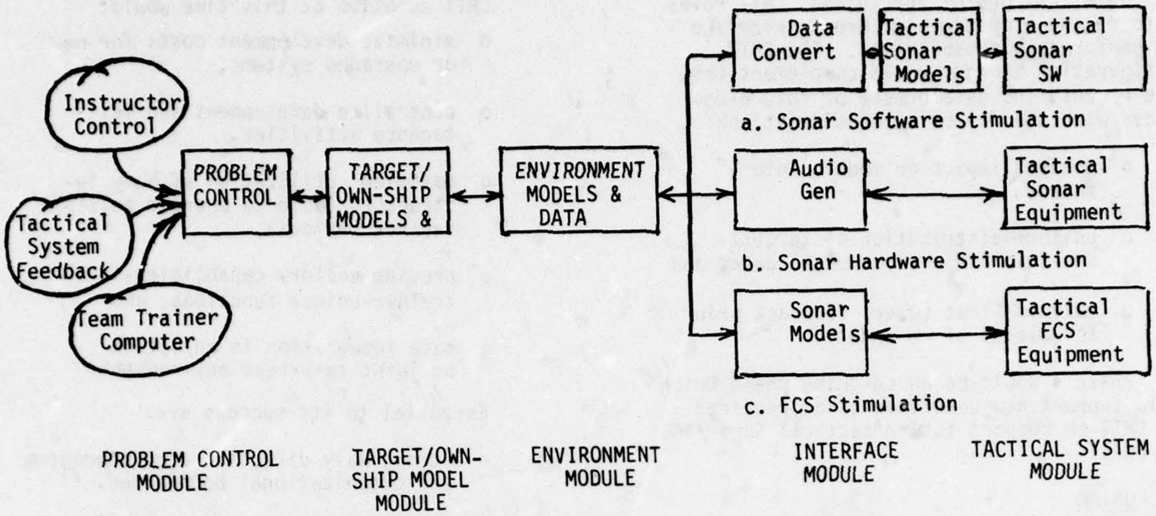


Figure 2 - COMMON MODEL TEAM TRAINER (CMTT)

PROBLEM CONTROL MODULE	TARGET/OWN-SHIP AND ENVIRONMENT MODULES	INTERFACE MODULE	TACTICAL SYSTEM MODULE
<u>Current Situation</u> o Different Abilities o Different Approaches o Different Interfaces	o Various Models, both oceans and targets o Various Data Sets	o Trainer Unique Implementation and Approaches	
<u>Phase 1 - Analysis and Standardization</u> o Define Requirements (A-level spec) o Standardize Interfaces (IDSs)	o Select all Parameters of Interest o Identify Model and Data Requirements (A-level spec) o Standardize Model and Data Definitions o Standardize I/O Requirements (IDSs)	o Define Impact on Existing Trainers	o Define Tactical Mods to Support CMTT Problem Control
<u>Phase 2 - Near-Term Implementation</u> o Design and Validate Problem Control Module	o Design CMTT Target and Environment Module o Validate Target and Ocean Models and Data	o Design and Validate CMTT Interface	o Design Tactical Mods to Support CMTT Problem Control
<u>Phase 3 - Long-Term Implementation</u> o Deliver to Installed Trainers: oo 21B64, TSOT, FBM SOT oo 21A Series, SCST, Mk 117 FCS o Develop for New Trainers: oo ISPE SOT oo SSN Re-engineered Combat System (RECS) oo Re-architected TSOT			
<u>Phase 4 - Maintenance</u> o Develop Plans for Problem Control and Target/Own-Ship and Environment Module Maintenance		o SYSCOMS Maintain Tactical System and Interface Modules	

Figure 3 - CMTT - DEVELOPMENT APPROACH SUMMARY

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IMPLEMENTING AIRCREW JUDGMENT TRAINING

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INTRODUCTION - THE PROBLEM

A fighter pilot delays his lag roll for an extra second--and instead of flying too close to his target, falls into a perfect shot position; his timing is the result of years of experience. A Landing Signal Officer (LSO), guiding aircraft aboard his carrier, calls a pilot for power a moment before it is needed and thus prevents a settling approach; his acute sensitivity has taken hundreds of hours to develop. A Tactical Action Officer (TAO), in the Combat Information Center of his ship, correlates all of the information from an ambiguous radar signal with the weapons available to him and correctly assigns ship missiles to a low-altitude bomber; long months of training and practice have made the difference between survival and disaster.

Each of these jobs--and there are many more like them in the armed forces--is an example of what is generally called judgment. That is, each job requires more than perceptual or motor skills. Jobs such as these require the ability to select among methods of problem solving, to weigh alternatives under stress and with limited information, as well as the ability to be innovative when the situation requires. No one can argue that judgment is not a valid reflection of trained performance. Few, however, can define judgment in a fashion which is usable for efficient training development. The major stumbling block in previous efforts to develop methodologies for judgment training has been their attempt to work with too global a definition of what judgment is. This paper reviews some recent work in this area and suggests potential solutions to the problem of judgment training (specifically, for aircrew tasks) which, though limited in scope, lend themselves to relatively easy implementation.

WHAT IS JUDGMENT?

One of the reasons, perhaps the major reason, why it is so difficult to obtain a useful definition of judgment is the large variety of performances to which the term judgment is applied. We are interested in judgment by the military equipment operator or tactical decision-maker, and thus we can confine ourselves to those military jobs which require judgment performance. A prime example is the job of the fighter pilot who has to fly his aircraft to a position where he can use his weapons against an active, thinking opponent who attempts to counter the fighter pilot with maneuvers of his own. It is this task which really separates the wheat from the chaff; i.e., the superior from the average pilot, or those who have good judment from those who don't. Two pilots may fly perfect practice maneuvers, each may know the capabilities of his aircraft and weapons, and each may possess the same levels of physical coordination and intelligence. Yet, during actual or simulated combat, one pilot achieves consistent victories while the other struggles just to avoid losing. What is the crucial difference? Is it primarily cognitive or affective in nature? What is the best way to describe this difference in a manner useful for training and training development?

A report, sponsored by the Federal Aviation Administration (Jensen & Benel, 1977), described pilot judgment as consisting of two components: 1) a cognitive component which deals with the establishment of alternative actions and the selection among them, and 2) an affective component or motivation which effects such selections among the alternatives. In a later paper (1978), Jensen expanded this definition to include a *continuum* between judgments which are perceptual and those which are cognitive, as a function of cognitive complexity of tasks and decision time (Figure 1).

PERCEPTUAL JUDGMENTS — COGNITIVE JUDGMENTS

INCREASING COGNITIVE COMPLEXITY (AND DECISION TIME) →

Figure 1. Judgment Continuum Based on Cognitive Complexity and Decision Time (Jensen, 1978)

According to Jensen, primarily perceptual judgment is associated with low cognitive complexity and little time available for decision making. At the other end of the continuum one finds more analytical forms of judgment, called cognitive judgment, under conditions of high cognitive complexity and plenty of available decision making time. This definition is the result of an extensive literature review and an in-depth analysis effort which included work that dealt with the judgment phenomenon in the context of a variety of jobs from aircrews to physicians.

Another study emphasizes the selection characteristics of aircrew judgment tasks (Saleh, et al. 1978) by proposing a training approach which teaches how to select among the relatively clear problem-solving techniques which are currently the "bread and butter" of most flight training programs. The need for a higher management scheme is identified in this study for sophisticated aircrew performance; an organized strategy to coordinate problem solving methods, to select and apply the most promising candidates. The skill of selecting among problem solving techniques has also been identified by Gagne and Briggs (1974), who call such skills "cognitive strategies". The position of these skills in the hierarchy of cognitive performances is shown in Figure 2. Gagné implies in his taxonomy that these cognitive strategies are internally organized (i.e., it would appear that these selection schemes are developed uniquely by each individual, over time and as a function of experience). Little can be said regarding the training of these strategies except that conditions should be made favorable for their acquisition.

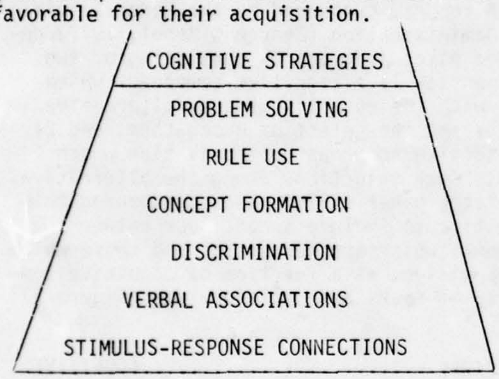

Figure 2. Intellectual Skills (Gagné and Briggs, 1974)

It would seem that judgment performance is characterized by the following components; although each model may emphasize different features, the basic properties appear to be:

1. Judgment involves a cognitive factor for generating candidate problem solutions, and strategies for choosing among them;
2. Judgment can involve selection strategies which manipulate probabilistic information--not all aspects of a situation may be known, but choices must still be made;
3. Judgment may be stress-dependent, in that motivation must exist to affect choices--if stress becomes extreme, however, judgment performance may be degraded.

Now, these definitions of judgment are all relevant to judgment performance, but are they all relevant to judgment training? Of the previously mentioned studies, those which propose training methods usually attempt to include all aspects of judgment in their programs. Such efforts are ambitious, and might be quite effective if properly implemented, but cost and personnel constraints weigh against this approach. What is left is a partial implementation of broad-based strategy for judgment training, or complete implementation of training focused on selected judgment characteristics. A case will be presented for the second option later in this paper.

WHAT IS JUDGMENT - REALLY?

The definitions of judgment presented so far are all adequate to explain at least parts of the judgment task; the Jensen scheme appears to be the most comprehensive. What is the concept, however, of judgment by those who must actually teach it? It is the evaluation of current training (and its improvement, if possible) which is the focus of this paper and this conference. It seems that the word "judgment" is used in its broadest sense by the aircrew training community, and this conceptual latitude has resulted in only diffused efforts to help students acquire judgmental skills.

By way of example, a large portion of pilot training effort is expended in teaching judgment during landing. Runway line up, approach attitude, and timing of the landing flare are all spoken of as demonstrations of pilot "judgment", and instruction directed at such skills is considered judgment instruction. A closer examination, however, reveals that such activities are really examples of perceptual discriminations (in the Gagné system) or perceptual judgments which occupy (in the Jensen scheme) only a narrow band of possible judgment performance. Thus, the part can be frequently mistaken for the whole, with two implications for training.

1. If lower level skills are considered to represent judgment, then true judgment tasks may receive a leaner portion of instructional attention, or
2. These lower level skills may be approached with incorrect instructional strategies in the belief that the tasks are something other than what they really are.

This condition is not at all uncommon in the aircrew training community and reflects --at least in part--the lack of clear concepts regarding judgment and its components. The problem extends to selection procedures for pilot candidates which seem to have reached a

ceiling of success; attrition rates, always a drain to training costs, have not been significantly reduced in many years. Furthermore, the competence of even graduate pilots is not uniform, as the earlier comparison of fighter pilots exemplifies. A recent study, supported by the McDonnell-Douglas Company (1977), attempted to discriminate those qualities which characterized the superior fighter pilot. Despite a review beginning from World War I and proceeding through Vietnam, no clear factors were found which could serve as predictive indices of fighter pilot success. Unambiguous factors would have a quite significant impact on selection and training; it is entirely possible that this search was not more successful because elements of judgment, of decision-making under combat stress, were not sufficiently defined.

Two approaches to judgment and training have been discussed--the theoretical analysis of judgment (and its training implications), and the current understanding of judgment at the field training level (with its resulting implications). Obviously, the two can be reconciled to the benefit of both, but how can this be accomplished expeditiously and with minimal impact on current training resources? Once again, a case can be presented which *permits full implementation* of training for components of judgment performance (rather than limited applications of a full definition) and this case will be examined next. The behaviors which are now considered aircrew "judgment" must first be broken down into training domains, those critical components which remain must be accommodated in the training program, and the effects of stress must be included; all of this, hopefully, at minimal expense.

REDUCING THE JUDGMENT DOMAIN

Taking note of the training situation for teaching landing performance cited earlier, the first step in formulating a plan for judgment instruction is to reduce its domain. This would involve an examination of each skill or scenario in a given training program and assignment of that skill/scenario to the type of learning which it truly represents. As stated before, not all flight tasks are really higher level judgment skills; in the landing example, a perceptual discrimination is being taught (i.e., the ability to detect whether visual cues are "right" or "wrong" for the desired position; once this is known, what to do in response becomes a matter of rule use--the reader is referred to the Gagné hierarchy, Figure 2). The point of this example is that existing ISD principles can be applied, once the skill is identified as belonging to the more deterministic types of learning. Furthermore, the ISD techniques chosen for this skill are appropriate; that is, ISD techniques relevant to perceptual discrimination and rule use are used to teach those skills, and this might not be the case if the skills were thrown into the grab bag known as "judgment". Judgment is popularly thought of as being a function of experience. It is not unreasonable, therefore, to trust the improvement of substandard or average performance to additional experience with the particular task. In this example, marginal landings may result in assignment of additional practice (for better judgment) when a quicker, cheaper solution would be presentation of correct runway "sight" pictures to the pilot, to improve his discrimination performance. The latter method was applied with good effect by the second author while conducting research at Williams Air Force Base, Arizona.

This principle applies up through fairly complex levels of learning, including problem-solving and concept mastery. If a fighter pilot is consistently executing an inappropriate maneuver for a given tactics situation, it might be the case that he has not established a necessary problem-solving routine (e.g., "I'm closer to a sparrow shot than I am to a sidewinder shot, but at this altitude the sidewinder has a better chance of success so I'll continue to work for the "winder envelope"), or has not mastered a critical concept, (e.g., "I can pull up and turn behind this high bogey, but when I get there I'll be too slow because whenever you gain altitude, you lose airspeed or energy, so I'd better add power now"). To the instructor, these cases may appear as instances of bad judgment when, in fact, they represent weaknesses in lower-level skills, which current ISD methods should be capable of handling.

In summary, it can be stated that judgment is a complex range of skills which may be manipulated under external conditions of time and stress. To make the process of judgment training more manageable, it is important to first establish what judgment is not; the remaining domain of skills can then be given the full attention required to teach them.

TRAINING FOR JUDGMENT

Those characteristics which were found to apply to judgment tasks (generation and selection of alternatives, probabilistic input, and stress effects) still account for a large and critical realm of the training mission. Such tasks as altitude positioning, airspeed and aircraft formation during the attack vector, and the myriad decisions involved in combat maneuvering during tactical engagements all include significant cognitive and affective components which comprise judgment performance. Jensen (1978) proposes a comprehensive plan for training judgment in general; what is proposed here is an abbreviated strategy for implementing some areas of judgment training on a more limited (and hopefully, more economical)

scale.

First, the probabilistic nature of the flight task must be appreciated. Combat maneuvering against a thinking, skilled, aggressive opponent always implies the risk that the assumptions about his battle plan and his abilities are wrong. Decisions must, nevertheless, be made if the fighter pilot is to establish his own plan. Although hindsight may permit a perfect analysis of what tactics should have been employed, the pilot in combat does not have the luxury of complete problem input and must make the best (i.e., most accurate and reliable) assessments that he can in a hostile environment. A simple decision paradigm is shown in Figure 3. At each level of the decision-making process, uncertainty exists regarding the results of that level. For example, if the problem cannot be precisely defined (due, say, to a lack of sufficient cues), then alternate solutions for two or more possible problems may have to be generated at the second level in this fashion, uncertainty is cumulative; if the decision-maker is unable to constrain or order the results of each phase--through additional input, training, or a judgmental decision--the entire process becomes unwieldy and a "random guess" may result.

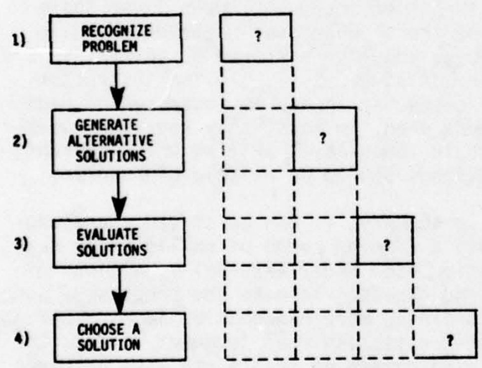

Figure 3. Judgment Under Uncertainty

The worst case for making a selection among alternatives is when each alternative is equally likely to the person who must make the selection; the more alternatives available, the lower the probability that any choice, at random, is the optimum one. There may in fact be a priority ranking or a probability distribution of the alternatives, but if this is unknown the decision is, at worst, a chance event. Now air combat training is far from such a random situation, and the novice pilot enters each tactical engagement with an extensive set of skills intended to present him with a realistic assessment (that is, one which accurately corresponds to the actual conditions) of each situation. The complexity of any scenario, however, can easily generate conditions for which no such ready-made assessment exists and the pilot is required to do his own analysis of the novel conditions and make an innovative or unusual choice of actions. Those pilots who are best able to appropriately respond to unexpected, complex events can be said to possess the best "judgment". Such pilots are frequently those with the most extensive and varied experience. What is suggested here is that a pilot (or any person who exercises true judgment) learns, over time, to modify an essentially random set of alternatives into an ordered set which permits the optimal choice for a given set of external conditions; a strategy is established for figuring out what is most likely to succeed and what is not.

Any training system which can facilitate the efficiency of this mechanism (somewhat akin to "cognitive strategies" in the Gagné hierarchy) or shorten its acquisition, should be quite valuable. Two methods for achieving this are suggested:

1) Situational Control--Although most training programs are carefully structured to present situations (i.e., simulator and flight events) which enhance perceptual/motor and procedures learning, little emphasis has been given to the presentation of situations which teach judgment performance. This is not to say that this training is absent, only that it has received insufficient attention in relation to its significance. If, as is proposed, judgment skills are a function of accurate selection among alternative actions, then the presentation of situations which match real-world probabilities should provide the shortest method for acquiring an understanding of those probabilities. Thus, a realistic probability distribution can be instilled in the flight student without the requirement to know the details of his internal decision-making processes. An academic example of this approach is the "situational training" of the Air Force, which attempts to develop prudent response strategies based on scenarios of emergencies rather than training each response procedure independently.

2) Academic Control--This approach was treated quite well in the Saleh (1977) study and involves an analysis of strategies for choosing between alternative courses of action and training these cognitive skills in addition to problem-solving procedures themselves. This approach is more complex and costly than the gross analysis required for the prior method, but is much more comprehensive and makes up a major part of the Jensen plan.

A simpler application of this approach is the presentation of scenarios which require the flight student to practice judgment skills; that is, configurations of flight tasks and

procedures into groups which tax the student's coordination of individual tasks and encourage the rapid development of cognitive strategies. As skills are taught through current syllabi, students learn an increasing number of procedures, but are left largely on their own in the establishment of coordination strategies. Again, an in-depth analysis of such strategies is not required--only the assembling of realistic and significant scenarios, and their incorporation into judgment training sequences of existing programs. A variation of this technique is currently employed for F-14 aircrew training which involves the presentation of a "canned" tactical engagement to the student. This is accomplished with the playback features of the air combat maneuvering range (ACMR), which can display a recorded flight in three dimensions. The entire event is shown, followed by a step-by-step replay of key maneuvers (much like a detailed account of a chess game), allowing the student to comment on or evaluate each decision point for himself. Once the student has become familiar with each component of the engagement and its overall "flavor", he is then ready to fly in an identical situation and make use of the strategic foundations he has developed through prior analysis; he already has a sophisticated set of algorithms--based on experience--regarding what will work and what will not.

The final major characteristic of judgment performance--stress effects--remains to be considered. Stress can enhance skilled performance by generating higher levels of motivation, but this is true only to a point, beyond which performance is degraded. In general, the lower the level of training or the more complex the skill, the greater the degradation for any given level of stress. Training should profit from those methods which can keep stress low enough to permit application of those skills.

Obviously, confidence in one's skills has a lot to do with how much stress can be self-generated precisely because the student is not sure of his procedures and skills. The solution of ACMR playback, discussed previously, is also relevant in this context because the student is allowed to analyze and understand a complex, dynamic event at his own pace; this luxury is not a usual application of such training media but a conversion like this is not impossible for simulators, part-task trainers, mission recorders, etc.

SUMMARY

As technology provides the means for handling the simpler tasks of most military jobs, the role of the equipment operator as a decision-maker, required to exercise complex judgment, becomes more critical to the military mission. The requirement grows, therefore, for the instructional design community to accommodate the special demands for judgment training in new and existing programs; indeed, the requirment has already existed for some time now.

Several studies of judgment and judgment training have been presented here. Each of these efforts has proposed a training implementation plan, some more extensive than others. This paper has attempted to evaluate the most practical features of each judgment analysis and convert them to training suggestions which could be easily and inexpensively incorporated into ongoing programs, including:

1. Reducing the domain of tasks which actually represent judgment performance,
2. Training this judgment performance using control of learning situations and academic presentation, and;
3. Considering (and, therefore, reducing) the effects of stress.

These suggestions are intended as a minimal cost, minimal intervention approach to fulfill the need for training judgment. Eventual expansion of these ideas could, hopefully, result in a comprehensive program along the lines of the Jensen proposal.

REFERENCES

Gagné, R. M., & Briggs, L. J., Principles of Instructional Design. New York: Holt, Rinehart, and Winston, Inc., 1974.

Jensen, R. S., and Benel, R. A., Judgment Evaluation and Instruction in Civil Pilot Training. Report No. FAA-RD-78-24 by Aviation Research Laboratory, Univ. of Illinois, December 1977.

Jensen, R. S., Pilot Judgment: Training and Evaluation. Proceedings of the 11th NTEC-Industry Conference, Nov. 1978, pp. 71-83.

Saleh, J., Leal, A., Lucaccini, L., Gardiner, P., & Hopf-Weichel, R., Analysis of Requirements and Methodology for Decision Training in Operational Systems. NAVTRAEQUIPCEN Tech Report No. 77-C-0005-1, February 1978.

Youngling, E. W., Levine, S. H., and Mocharnuk, J. B., Feasibility Study to Predict Combat Effectiveness for Selected Military Roles: Fighter Pilot Effectiveness. Report No. MDC E1634 by McDonnell-Douglas Astronautics Co., East, 29 April 1977.

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